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Modeling the Adoption Process of the Flight Training Synthetic Environment Technology (FTSET) in the Turkish Army Aviation (TUAA)

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December 2006

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13. ABSTRACT *(maximum 200 words)*

The motivation for using Flight Training Synthetic Environment Technology (FTSET) in military aviation is to create a cost-efficient and a risk-managed training environment. However, deciding on the appropriate mix of synthetic versus actual flight training remains a great unresolved issue. Further, FTSET usage and its adoption level may vary across the aviation community and flight training curricula.

TUAA has employed FTSET in helicopter flight training since 1990. Since then, it has exhibited three different FTSET Support Usage patterns, which include an initial phase of lower support rates until 1997, a substantial increase phase from 1997-2001, and a leveling-off phase, where growth stagnated, from 2001-2006. We hypothesize that these sequential phasing can be explained in terms of the organizational culture in which the FTSET is employed, organizational changes that favor FTSET usage and increasing FTSET expertise in the usage, and the current FTSET's limited technical capability and its sole support for one type of helicopter.

To test our hypotheses we develop a systems dynamics model of the FTSET adoption process (AP) that has three interrelated sectors: Technology Improvement and Acquisition, Technology Adoption, and Technology Discarding. The Diffusion Model is also used as a framework to help explain the TUAA's FTSET AP from 1990 to 2006. The purpose is to understand this AP and to generate a policy for the current and future FTSET AP.

14. SUBJECT TERMS Flight Training Synthetic Environment Technology (FTSET), Flight Training Curriculum, Flight Simulators (FS), Synthetic Training Devices (STD), Systems Dynamics (SD), Adoption Process (AP), The Diffusion Model, Diffusion of Innovations Theory, Source-, User-Centered Adoption Models, Technology Awareness, Transfer of Training, Perceived Ease of Use (PEU), Perceived Usefulness (PU).			**15. NUMBER OF PAGES** 101
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MODELING THE ADOPTION PROCESS OF THE FLIGHT TRAINING SYNTHETIC ENVIRONMENT TECHNOLOGY (FTSET) IN THE TURKISH ARMY AVIATION (TUAA)

Ömer Boztaş, Major, Turkish Army

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I. INTRODUCTION

A. BACKGROUND

Flight training methodology and the use of simulator technology have held a great place in aviation research. The unknowns in human behavior and the complexities of human-machine interaction constitute the center of this research and experimentation. The biggest motivation behind developing better flight training technologies is to understand human behavior in order to avoid human associated risks. As indicated in Figure 1, human error has always been an important risk factor in aviation accidents.

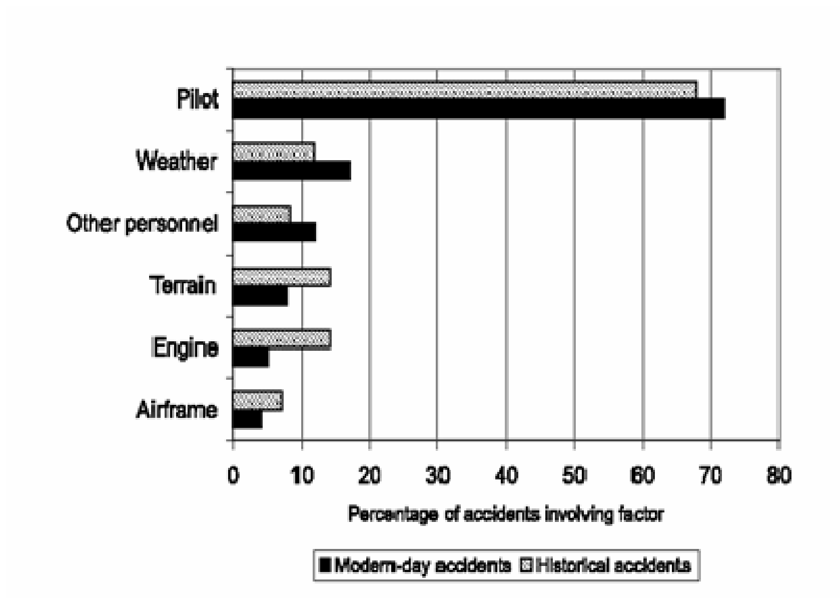

Figure 1. Historical Comparison of Human Factors in Aviation Accidents[1]

The interactive systems widely used in pilot training are generally referred to as synthetic training devices (STD). STD have been in use roughly since World War I. Since then, the need for training large numbers of aviators encouraged the development of the new discipline of aviation psychology and new tests were introduced. These developments also led to new devices to aid in the assessment of the aptitude of

1 Alan Hobbs, “Human Factors: The Last Frontier of Aviation Safety,” The International Journal of Aviation Psychology 14(4) (2004): 339.

prospective pilots[2]. The Link Trainer was developed in 1927-1929 and it was the most successful and well-known trainer of its era, and in STD history[3]. The number of these training devices, and their capabilities significantly increased, especially after World War II.

Today, STD support almost every phase of aviation training for both civil and military applications. The main motivation for their use is to create a cost-efficient and a less risky training environment. While STD became an integral part of all commercial airline operations in the 1960s, they have only recently gained acceptance for international military flight training during the last decade[4]. There are several civil flight schools that have pilot training curriculums based on a "100% simulator flight approach". The simulators utilized for this purpose are usually called "flight simulators (FS)" and are classified according to the Joint Aviation Authorities[5] (JAA) and/or Federal Aviation Administration[6] (FAA) Rules and Regulations.

According to the latest developments in military FS applications, up to 75% of required flight training hours in some programs are performed in the synthetic environment (SE)[7]. For example, Flight School XXI (FS XXI)[8] was motivated to update its curriculum and incorporate more simulator flights as a result of a substantial cut in the availability of training funds. The stated program objectives were to make the US Army Aviation Flight School more efficient and to increase the war fighting capability of

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2 Ray L.Page, "Brief History of Flight Simulation," R.L. Page and Associates: 2.

3 L.L. Kelly, "The Pilot Maker," (1970) : cited in Ray L. Page: Brief History of Flight Simulation, 2.

4 Ray L.Page, "Brief History of Flight Simulation", 2.

5 The Joint Aviation Authorities (JAA) is an associated body of the European Civil Aviation Conference (ECAC) representing the civil aviation regulatory authorities of a number of European States who have agreed to co-operate in developing and implementing common safety regulatory standards and procedures. (JAA Official Webpage).

http://www.jaa.nl/introduction/introduction.html (25 November 2006).

6 Federal Aviation Administration (FAA) is responsible for the safety of civil aviation and is a part of the US Department of Transportation. (FAA Official Webpage)

http://www.faa.gov/about/mission/activities/ (25 November 2006).

7 Tim Mahon, "Sims with Service," Training and Simulation Journal (2006), http://www.tsjonline.com/story.php?F=27865576US (19 June 2006).

8 US Army Aviation School redesign effort. The FS XXI Training Implementation Plan Presentations (26 December 2001).

graduates[9]. This plan required simulation-based training flights for 35.7% - 42.5% of all training flights for Phases I and II, “The Common Core” and “The Advanced Track” respectively[10].

Currently, the reduction in actual flight hours and the associated cost savings via the use of advanced flight training synthetic environment technology (FTSET) seems to be the primary goal of almost every stakeholder in the aviation sector. The identical cockpits and the highly realistic virtual environment effects are considered the two most important features of recent FTSET, and may help influence the aviation community to convert to more simulator-based flights. These developments are closely related to and parallel recent developments in computer and software technologies. Figure 2 shows an example of helicopter technology-related software development over time. It demonstrates the exponential increase in software growth for helicopter technologies.

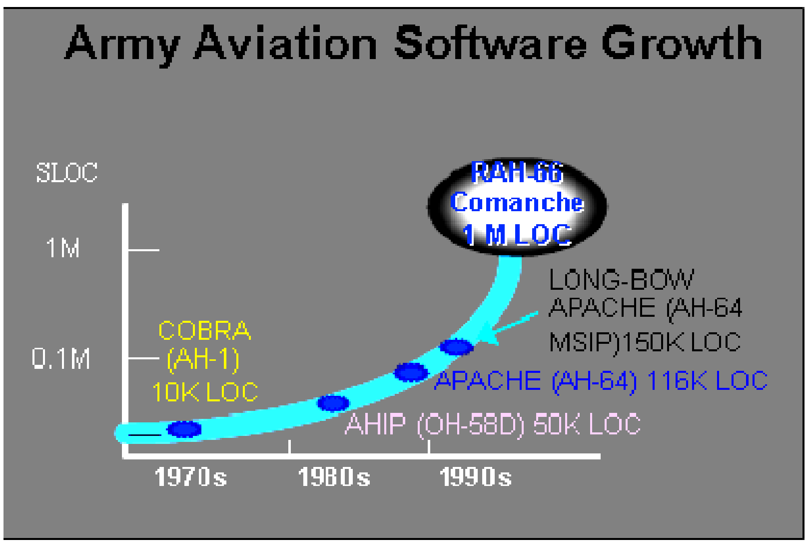

Figure 2. US Army Aviation Software Growth in terms of lines of code (LOC)[11]

9 John E. Stewart III, John A. Dohme, and Robert T. Nullmeyer, “Optimizing Simulator-Aircraft Mix for US Army Initial Entry Rotary Wing Training,” Technical Report 1092 (March 1999): 6.

10 The FS XXI Training Implementation Plan Presentations (26 December 2001 through 23 Jan 2002): “The Common Core” is used for initial helicopter training for the beginners while “The Advanced Track” is mentioned for advanced helicopter training in the FS XXI Training Implementation Plan Presentations.

<www.fa-57.army.mil/refs/bfgs/TRADOC-Transf/FS%20XX> (25 August 2006).

11 Naval Postgraduate School / Graduate School of Business Public and Policy - MN3331: Principles of System Acquisition and Program Management Lecture Slides; 9-1 Software Intensive DoD Sytems.ppt.

Resolution level[12], iteration rate[13], latency rate[14], models and their real time effects are some of the features that determine the level of fidelity[15] in FTSET and support realistic training in FS. The level of fidelity is accepted as the primary determinant of the quality of FTSET. The two types of fidelity mentioned in the literature are objective fidelity and perceptual fidelity and they are described as follows[16]:

> Objective fidelity in a simulator refers to the physical correspondence between the flight simulator and the aircraft. Presumably, engineering techniques can be applied to measure both the aircraft and the simulator, yielding an index of objective fidelity.
>
> Perceptual fidelity refers to the relationship between a pilot's subjective perceptions of the simulator and the aircraft. It also refers to the comparative sets of pilot performance and control strategies in the simulator and the aircraft.

When evaluating the required fidelity level of FTSET, both the objective and perceptual fidelity must be considered, along with the specific mission needs. For example, pilot candidates benefit from a variety of relatively low fidelity training devices and simulators, while experienced pilots receiving refresher training tend to require high fidelity simulators[17]. Further, military pilots also prefer higher fidelity FS. This stems from their need to feel as if they are flying real missions in realistic environments. The responses offered in a survey (Lafçı, 2005) - applied to 145 Turkish Army Aviation

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12 Resolution Level is the amount of detail or degree of aggregation employed in the model or simulation used <http://www.jhuapl.edu/techdigest/td2604/coolahan.pdf> (02 December 2006).

13 Iteration Rate explains image generator (IG)'s speed at which the FS's visual system responds to given commands.

14 Latency Rate is the level of time lag that occurs between the control signal sent to the simulator processor and the simulation effect produced as an output.

15 The degree to which a model or simulation reproduces the state and behavior of the real world, or the perception of a real world object, feature, condition, or chosen standard in a measurable or perceivable manner; a measure of the realism of a model or simulation. Fidelity should generally described with respect to measures, standards, or perceptions used in assessing or stating it, See accuracy, precision, resolution, repeatability, model/simulation validation. This definition was developed by Fidelity Working Group for DoD Simulator Interoperability Standards Organization (1998) and quoted in Archie E. Dillard, "Validation of Advanced Flight Simulators for Human Factors Operational Evaluation and Training Programs,": (2002): 35.

16 Michael E. McCauley, "Do Army Helicopter Training Simulators Need Motion Bases," Technical Report 1176, (February 2006): 4.

17 Richard S. Gibson, "Certification of Training," in *Human Factors in Certification* (Mahwah, New Jersey and London: Lawrence Erlbaum Associates, Publishers, 2000), 156.

(TUAA) pilots, show that as many as 80.7%-86.4% indicate strong agreement in the importance of better fidelity, the increased quality of the visual system, and the existence of six degrees of freedom (DOF)[18] in the motion platform. The end-users accept some of these aspects of FS as indispensable; however, they are also cost multipliers to the acquisition professionals. McCauley (2006), for example, discusses this issue while investigating US Army helicopter training simulators' need for motion bases[19]

> User acceptance (pilot preference) is a third perspective on the value of simulator features. How much value should be placed on simulator features that are preferred by pilots but generate no measurable training effectiveness? This is a value judgment that is not amenable to empirical research but may be important to an acquisition program manager or a military commander responsible for training and readiness.

In addition to technical features, there are several other concerns that must be taken into account in the use of FTSET. McCauley (2006) states that there is little evidence supporting the common belief that more fidelity equates to better training[20]. In other words, the higher technical features of FTSET might not always generate meaningful results for the end-user. A more appropriate way to assess the favorability of using FTSET is to determine the degree to which FTSET training can be transferred to actual mission flight or the level to which training effectiveness can be maintained. Otherwise, it would be less cost-effective to install and maintain a highly expensive FTSET. The end-user should not pay excessively for a less favorable transfer of training (TOT), and/or no evidence of training effectiveness (EOTE). These two performance metrics, TOT and EOTE, are defined as follows[21]:

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18 Aydın Lafçı, "The Importance of Simulator Usage in TUAA Flight Combat Readiness Training and determining the optimum usage rates" (M.S. thesis, Turkish Military Academy Defense Sciences Institute of Technology Management, 2005).

19 Michael E. McCauley, "Do Army Helicopter Training Simulators Need Motion Bases," Technical Report 1176, (February 2006): 2.

20 Ibid.

21 L.H.Taylor, G.Lintern and J.M.Koonce "Quasi-Transfer as a predictor from simulator to airplane," (1993): quoted in John E. Stewart III, John A. Dohme, and Robert T. Nullmeyer, Optimizing Simulator-Aircraft Mix for US Army Initial Entry Rotary Wing Training (US Army Research Institute for the Behavioral and Social Sciences Technical Report 1092, March 1999): 1.

> A flight simulator is effective if the skills that a pilot learns in the simulator can be performed in the aircraft; that is, if the skills transfer from the simulator to the aircraft. The effectiveness of training in a flight simulator is a function of the amount of skill that transfers. Its cost-effectiveness in a pilot training program depends on the amount of skill that transfers to the aircraft as well as the ratio of simulator to aircraft operating costs.

Since the introduction of advanced FS, the correct mix of synthetic flight (SF) versus actual flight training has been a big issue. This is evidenced by the number of studies on optimizing the simulator-aircraft mix. In Dufaur (2004), the simulator-aircraft mix percentages were given as 30% for initial flight training, 80% and above for aircraft type training, 50% for instrument flight rules (IFR) training, 50% for navigation and tactical flight training, and 30-80% for mission specific training[22].

Two other highly visible studies were performed by the TUAA and US Army Research Institute (ARI) for the Behavioral and Social Sciences. The TUAA study, based on an analysis of questionnaire results[23], found that the appropriate simulator-aircraft mix flight ratio for TUAA pilots was 50.82% regarding all phases of helicopter flight training. However, this ratio should be evaluated and verified over time by two significant metrics, TOT and EOTE since the questionnaires naturally include subjectivity in them.

Training effectiveness of FS should also be evaluated before integrating them into training systems. This is the most common challenge directed against FS's integration into training curriculums and the studies on correct simulator-aircraft mix. Caro (1973) stated this problem as follows[24].

> Most personnel who design and integrate simulators are engineers, not behavioral scientists…..Much more attention has been paid to the

22J.Alain Dufaur, "Helicopter Flight and Mission Simulation (Presentation)," International Conference on Development in Aviation Training, Mumbai (2004): quoted in Aydın Lafçı: "The Importance of Simulator Usage in TUAA Flight Combat Readiness Training and determining the optimum usage rates" (MS, Turkish Military Academy Defense Sciences Institute of Technology Management, 2005).

23 Aydın Lafçı, "The Importance of Simulator Usage in TUAA Flight Combat Readiness Training and determining the optimum usage rates" (M.S. thesis, Turkish Military Academy Defense Sciences Institute of Technology Management, 2005).

24 P.W. Caro, "Aircraft Simulators and Pilot Training," Human Factors (1973): quoted in John E. Stewart III, John A. Dohme, and Robert T. Nullmeyer, "Optimizing Simulator-Aircraft Mix for US Army Initial Entry Rotary Wing Training," (Technical Report 1092, March 1999), 2.

development of the simulator itself, than to the training program which supports it.

In the second study, US ARI proposed the analysis of the following areas for better use of STD [25]:

- The current training objectives.

- The measurement of trainee performance.

- The mix of aircraft and simulator (including other training devices) training.

- The integration of academic class work and flight training.

- The costs of each training phase and each instructional method.

- The effect of instructor pilot attitudes and beliefs upon training effectiveness.

- The effects of trainees' individual differences, e.g., personality, prior flight experience, attitude toward training, specific strengths and weaknesses, learning position and disposition toward feedback, upon training effectiveness.

- The structure of the curriculum.

The results of these two studies and an understanding of the metrics, TOT and EOTE, are important in shedding light on the adoption process (AP) of FTSET. The better utilization and faster adoption of FTSET might serve as a factor in cost savings, time savings, risk reduction, and efficiency[26] of flight training. These benefits could be maintained and improved by examining each organization's unique structure according to an overall analysis of the areas proposed by US ARI above.

There seems to be many opportunities in the FTSET market that can be exploited to enhance the development of cost-efficient flight training. Based on that, the use of FS is on the rise and the trend continues to grow in favor of more simulator hours. However, it is still not certain which type of flight training devices (FTD) should be accepted as the

25 John E. Stewart III, John A. Dohme, and Robert T. Nullmeyer, "Optimizing Simulator-Aircraft Mix for US Army Initial Entry Rotary Wing Training," (Technical Report 1092, March 1999), 8.

26 Michael E. McCauley, "Do Army Helicopter Training Simulators Need Motion Bases," Technical Report 1176, (February 2006): 3.

primary substitute for the actual aircraft, and to what degree FS hours should be substituted for actual aircraft flight hours. There are two reasons for this dilemma. The first concerns the complexity of military aircraft and the military-specific mission flights, and the second concerns FTSET support capability which determines how realistically complex mission and the associated environment can be simulated.

A general definition for FTD proposed by the FAA is as follows[27].

> A full scale replica of an airplane's instruments, equipment, panels, land controls in an open flight deck area or an enclosed airplane cockpit, including the assemblage of equipment and programs necessary to represent the airplane in ground and flight conditions to the extent of the systems installed in the device does not require a force (motion) cueing or visual system; is found to meet criteria outline in this Advisory Circular[28] for a specific flight training device; and in which any flight training event or checking event is accomplished.

Both FTSET acquisition professionals and the technology developers should take into account generally accepted JAA and FAA regulations and be aware of the latest changes in these criteria. For now, based on the FAA's definition, it appears that training hours on computer-based training devices might not adequately substitute for actual flight hours; however, there will be steadily increasing demand for some type of certification of these hardware-software combinations for currency or refresher training[29].

As defined by FAA, force cueing and motion platform are not required for FTD; however, in Lafçı (2005), the majority of the TUAA pilots' sampled (86.4%)[30] accounted the existence of motion platform on FS as a significant requirement. Although, there is

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[27] Richard S. Gibson, "Certification of Training," in *Human Factors in Certification* (Mahwah, New Jersey and London: Lawrence Erlbaum Associates, Publishers, 2000), 157.

[28] Advisory Circular's give specific criteria required to obtain and maintain approval on commercial simulators to be used for flight crew training. The FAA Advisory Circular (AC) 120-45A specifies the evaluation and qualification requirements for six of a possible seven-level-of-flight-training device. Level 1 is currently reserved and could possibly include PC-based training devices and in quoted in Archie E. Dillard, "Validation of Advanced Flight Simulators for Human Factors Operational Evaluation and Training Programs": (2002): 34.

[29] Richard S. Gibson, "Certification of Training," in *Human Factors in Certification* (Mahwah, New Jersey and London: Lawrence Erlbaum Associates, Publishers, 2000), 157.

30 Aydın Lafçı, "The Importance of Simulator Usage in TUAA Flight Combat Readiness Training and determining the optimum usage rates" (M.S. thesis, Turkish Military Academy Defense Sciences Institute of Technology Management, 2005).

currently no scientific evidence explaining the training effectiveness of the motion platform, it might contribute to in-simulator performance, particularly for experienced pilots[31].

FS are classified differently than computer-based trainers. They are both classified and certified by JAA and FAA as Level A through Level D simulators, where Level D is the highest level of certification. New training simulators that meet this level or FAA Level C approval criteria can cost $15 million or more[32] (including the acquired system price). In addition to the original approval, all commercial simulators must be rechecked a minimum of twice annually, over the operational life of the equipment, to maintain approval[33]. Hourly simulator costs vary from around $300 to more than $1200, depending on the aircraft type and availability[34]. These concerns force small-scale aircraft operators, who purchase training or FS hours, to have their pilots trained on FS owned by big-scale aircraft operators, rather than acquiring and operating these complex and expensive systems themselves.

The other alternative is for an organization to acquire and use FS without external certification or classification and apply criteria according to the organization's specific needs. This method appears more logical and preferable for military aviation organizations, since they have more complex aircraft systems and mission needs, and unique (state-of-the-art technology) FTSET requirements. For example, the US Department of Defense (DoD) is now in the process of developing its own approval process[35].

Two additional examples include the TUAA School helicopter FS and US Army Aviation School 2B24 Synthetic Flight Training System (SFTS), neither of which have obtained certification from the JAA or the FAA. Despite this lack of certification, they have been in use actively and successfully for tens of years. Demir, May 2001, showed

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[31] Michael E. McCauley, "Do Army Helicopter Training Simulators Need Motion Bases," Technical Report 1176, (February 2006): 33.

[32] Archie E. Dillard, "Validation of Advanced Flight Simulators for Human Factors Operational Evaluation and Training Programs" (Foundations '02 V&V Workshop, John Hopkins University, 2002, 5).

[33] Ibid.34.

[34] Ibid.49.

35 Ibid.35.

that TUAA School helicopter FS have features which meet FAA AC 120-63 Helicopter Simulator Qualification Document Level B criteria[36] from both a software and hardware point of view.

TUAA has been using FTSET in helicopter flight training since 1990. As in other technology adoption processes, FTSET usage and its adoption in TUAA took some time to materialize and experienced a substantial increase after the late 1990s. In recent years, it has been observed that the trend in FTSET usage has been slowing down. It is generally believed that the current FTSET usage has leveled off because of its technological capability and will be discussed further in section III.A.1.

Recently, TUAA has executed a new FTSET procurement program to transition more simulation-based training flights into helicopter training curriculum by making use of advanced FTSET. The TUAA community believes that the newer technology's adoption cycle (AC) will be faster than the current system's since the acquisition plan and the system features have been tailored to capture more benefit in a shorter time.

B. RESEARCH QUESTION

In this project, the FTSET AP is examined, and the following questions are addressed:

1. Is it possible to constitute a FTSET adoption model for the TUAA?

2. Can factors; such as, technical quality of acquired systems, technology awareness and resistance, appropriate use of training environment, technology obsolescence trends, and customization levels of end-users, have causal relationships on the AP of FTSET?

3. Can the Systems Dynamics FTSET adoption model (built using *Stella Modeling and Simulation Platform*) be used to develop a TUAA policy for future technology acquisitions?

C. PURPOSE

The objective of this project is to model the FTSET AP in the TUAA by employing a Systems Dynamics Simulation Model using the *Stella Modeling and*

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[36] Murat Demir, "Simulation/ Simulator Applications in Training: Investigation and Qualification of a Helicopter Flight Training Simulator with Motion System; a Sample Computer Simulation Application" (M.S. thesis, Gazi University Institute of Science and Technology, 2001).

Simulation Platform. The Diffusion Model is used as a framework to help explain what TUAA has experienced as a FTSET AP from 1990 to 2006. The Diffusion Model is also evaluated to explain the experiences of the TUAA's current FTSET AP. The purpose is to understand AP and to generate a policy for prospective FTSET AP.

D. SCOPE

The project's scope is limited to the study of the TUAA Helicopter FTSET AP. The Helicopter FS studied in this research are located in the TUAA School and operated under the command of the Army Aviation School. The end-users referred to in this project, are the TUAA School instructor and candidate pilots, qualified TUAA helicopter pilots, and the TUAA organization itself.

FTSET AP variables used in building technology AP models and the probable policy implication for future system acquisitions are studied in this research.

E. SYSTEMS DYNAMICS PERSPECTIVE OF TECHNOLOGY ADOPTION

1. Diffusion of Innovations Theory

In Systems Dynamics (SD) literature; "adoption" and "diffusion" models are used to explain the dynamics of innovation processes, the adoption of new technology, as well as the escalation of epidemics in a society. The acceptance of new ideas and the resistance to innovation in organizations is also evaluated within this context. The adoption of new technologies is usually explained by the Diffusion of Innovations Model[37] and its S-shaped growth patterns. French Sociologist Gabriel Tarde plotted the original S-shaped diffusion curve as early as 1903 and it is still relevant because "most innovations have S-shaped rate of adoption"[38] (Rogers, 1995) as shown in Figure 3.

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37 Diffusion of Innovations Theory, *University of Twente Online* http://www.tcw.utwente.nl/theorieenoverzicht/Levels%20of20theories/macro/Diffusion (12 October 2006).

38 Ibid.

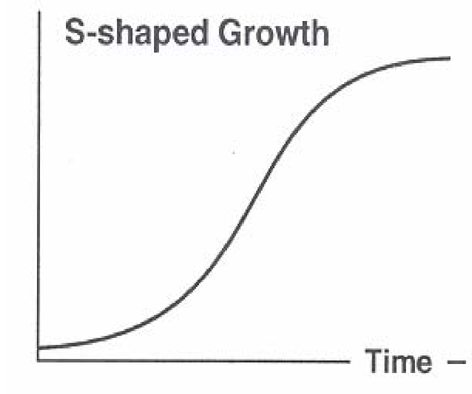

Figure 3. S-Shaped Diffusion of Innovations Curve[39]

In this study, the biggest challenge is adapting the Diffusion of Innovations Model, which is generally utilized by scholars to explain private sector adoption processes to the military organizational structure. Regarding innovation diffusion trends, the public sector and especially the military might deviate from the private sector for similar technologies. The private sector is generally better than the public sector in developing technology strategies[40]. As depicted by Botchway (1999) and shown in Figure 4, such strategies tend to be combinations of three elements – how organizations acquire, manage, and exploit their technological assets[41].

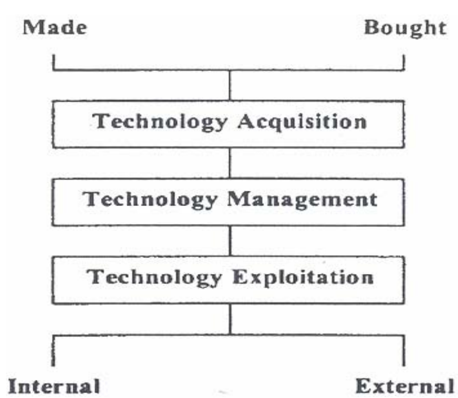

Figure 4. A Framework for Technology Strategy

39 John D. Sterman, Business Dynamics: Systems Thinking and Modeling for a Complex World (New York: Irwin McGraw-Hill, 2000), 108.

40 Quaye Botchway, George Goodall, "Diffusion of Technologies by Local Authorities: The Case of Manchester City Council, UK," Strategic Change 8 (1999): 271.

41 Ibid.270.

The Diffusion of Innovations Theory predicts that interpersonal contacts provide information and influence opinion and judgment[42]. In this context, positive attitude towards a technology is significant and is broadly discussed in the literature. For example, Agarwal and Prasad et al. (1997) argued that individuals' perceptions towards using an innovation are considered to affect their adoption behavior[43].

2. Technology Adoption Aspect of FTSET and Information Technology (IT)

A thorough review of the literature reveals that there are no relevant studies on adoption models for FTSET. However, the information technology (IT) domain closely models the FTSET AP in two ways. The first concerns computer and software technologies' common and intense use in each area of technology. The second concerns the human-associated behavior towards adoption of computer-based technologies since the rejection of such technologies is a notable problem in the IT domain[44]. A similar resistance can be found in the literature regarding FTSET. As stated by Stewart III et al. (1999), US Army Aviation did not adapt itself the research findings demonstrated increased training efficiencies as a result of the application of low cost simulators and automated, adaptive trainers to the Initial Entry Rotary Wing (IERW) programs[45]

> Prior to the mid '90s, the Army Aviation training community did not acknowledge a requirement for greater training efficiencies. The general rule was to retain the same number of "blade hours" in the curriculum and to resist attempts to increase reliance on simulation

In the IT domain, one of the most important measures of implementation success is its adoption and voluntary use by managerial, professional, and operating level personnel. This use is deemed a necessary condition for success, and resistance to

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42 E.M. Rogers, "Diffusion of Innovations," 4th ed. (1995): cited in, University of Twente Online http://www.tcw.utwente.nl/theorieenoverzicht/Levels%20of20theories/macro/Diffusion (12 October 2006).

43 R. Agarwal and J. Prasad, "Are Individual Differences Germane to the Acceptance of New Information Technologies," Decision Sciences, 30(2), 361-391 (1999): cited in Margherita Pagani, "Determinants of Adoption of Third Generation Mobile Multimedia Services," Journal of Interactive Marketing 18 (2004): 47.

44 Said S. Al-Gahtani: "Computer Technology Adoption in Saudi Arabia: Correlates of Perceived Innovation Attributes," Information Technology for Development 10 (2003), 58.

45 John E. Stewart III, John A. Dohme, and Robert T. Nullmeyer, "Optimizing Simulator-Aircraft Mix for US Army Initial Entry Rotary Wing Training," Technical Report 1092 (March 1999): 7.

computer systems by managers and professionals is a widespread problem[46]. Based on these observations, we consider the individual user's attitude and the associated organizational culture to be the two major determinants of FTSET AP support, and incorporate these into our model studies.

IT researchers agree that IT affects white collar performance and its adoption level is a key variable[47] in organizational effectiveness. As a result, one of the most important performance criteria in the business world turns out to be the adoption and the implementation of IT.

As noted in several IT studies (Al-Gahtani 2003; Au & Enderwick 2000, Heslin 1996; Rogers 1995), there are a number of common attributes which are the key to innovation diffusion, these include: relative advantage, complexity, compatibility, observability, and trialibility. For the purposes of this study, the Rogers' studies "Diffusion of Innovations" and these five attributes are helpful in modeling FTSET AP in the TUAA and determine the adoption rate of the associated technology. These attributes are defined in Al-Gahtani (2003), in his study of computer technology adoption as follows[48].

> <u>Relative Advantage;</u> is the degree to which an innovation is perceived as being better than the idea it supersedes. The degree of relative advantage is often expressed as economic profitability, social prestige, or other benefits. Diffusion scholars have found relative advantage to be one of the best predictors of an innovation's rate of adoption.
>
> <u>Compatibility;</u> is the degree to which an innovation is perceived as consistent with the existing socio-cultural values and beliefs, past experiences, and needs of potential adopters. Rogers suggests that the compatibility of an innovation, as perceived by members of a social system, is positively related to its rate of adoption.

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46 Said S. Al-Gahtani: "Computer Technology Adoption in Saudi Arabia: Correlates of Perceived Innovation Attributes," Information Technology for Development 10 (2003), 61.

47 R. Sharda, S.H.Barr, and J.C.Mc.Donnell, "Decision Support System Effectiveness: A Review and Empirical Test," Management Science, 34, 2 (1988): cited in, Detmar Straub, Moez Limayem, Elena Karahanna-Evaristo: Measuring System Usage: Implications for IS Theory Testing, (Management Science, Aug., 1995), 1328.

48 E.M. Rogers, "Diffusion of Innovations," 3rd & 4th ed. (1983 & 1995): cited in, Said S. Al-Gahtani: Computer Technology Adoption in Saudi Arabia: Correlates of Perceived Innovation Attributes, (IOS Press, 2003), 59.

Complexity; is the degree to which an innovation is perceived as relatively difficult to understand and use. Any new idea may be classified on the complexity-simplicity continuum. Some innovations are clear in their meaning to potential adopters whereas others are not. Rogers further suggests that the complexity of an innovation, as perceived by members of a social system, is negatively related to its rate of adoption.

Trialibility; is the degree to which an innovation may be experimented with on a limited basis. The personal trying-out of an innovation is a way to give meaning to an innovation, to find out how it works under one's own conditions. This trial is a means to dispel uncertainty about the new idea. Rogers suggests that the trialibility of an innovation, as perceived by the members of a social system, is positively related to its rate of adoption.

Observability; is the degree to which the results of an innovation are visible to others. The results of some ideas are easily observed and communicated to others. The results of some ideas are easily observed and communicated to others, whereas some innovations are difficult to observe or to describe to others. Rogers argued that the software component of a technological innovation is not so apparent to observation, so innovations in which the software aspect is dominant, possess less observability, and usually have a relatively slower rate of adoption. The observability of an innovation, as perceived by the members of a social system, is positively related to its rate of adoption.

Since the introduction of computer systems, one of the common bottlenecks to its adoption has been the complexity of the front-end interface. These computer-based systems must be made easier to use to encourage faster adoption. Ease of use in turn implies that computer systems must have a well engineered front-end interfacing as well as considerable built-in flexibility[49].

In addition to Rogers' five attributes, the "technology acceptance model (TAM)"[50] is generally accepted to explain technology adoption behavior in humans. Human perception of a given technology is again the leading determinant in explaining the AP of a technology. Two terms; the perceived usefulness (PU) and the perceived ease

49 Alan K. Graham, "Software Design: Breaking the bottleneck," IEEE Spectrum (March 1982): 45.

50 F. D. Davis, "Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology," MIS Quarterly 13(3), (1989): 319-340, cited in Margherita Pagani, "Determinants of Adoption of Third Generation Mobile Multimedia Services," Journal of Interactive Marketing 18 (2004): 47-48.

of use (PEU) are significant factors that should be considered in any technology adoption model[51]. These terms are discussed below.

> "The perceived usefulness" is defined as the degree to which a person believes that using that particular system would enhance his or her job performance while "the perceived ease of use" is defined as the degree to which a person believes that using a particular system would be free of effort.

These two factors are carefully considered in predicting the acceptance of FTSET in the TUAA because they are perceived to be the most important factors that end-users would consider in evaluating FTSET. This is because personal job performance enhancement through such technologies is attractive to TUAA personnel.

Empirical research (e.g. I-LAB- Bocconi University 2002, 2003) has shown that awareness, familiarity, and involvement are influential on attitudes toward using new services. These factors have also been accepted as important influences on PU and PEU[52].

51 Margherita Pagani, "Determinants of Adoption of Third Generation Mobile Multimedia Services," Journal of Interactive Marketing 18 (2004): 47-48.

52 Ibid.52.

II. METHODOLOGY

A. SYSTEMS THINKING AND MODELING APPROACH

The systems thinking and modeling approach considers a systems' complex and dynamic structure and attempts to analyze problems within these structures while preserving certain model boundaries. This approach is a perspective and set of conceptual tools that enable researchers to understand the structure and the dynamics of complex systems[53]. The use of SD is most effective when it is part of an ongoing learning system[54].

Since the introduction (1964) of SD[55], the concept has been utilized in several domains to address dynamic problems. SD models facilitate the strategic management of projects, determining measurement and reward systems, and evaluating risks and learning from the past[56]. Since the 1980s, large-scale research and development (R&D) projects such as software development have been supported and planned utilizing system dynamics philosophy[57]. Among the most significant developments are the models developed by Abdel-Hamid[58] and Lin[59] at NASA.

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53 John D. Sterman, Business Dynamics: Systems Thinking and Modeling for a Complex World (New York: Irwin McGraw-Hill, 2000), vii.

54 James M. Lyneis, Kenneth G. Cooper, and Sharon A. Els, "Strategic Mangement of Complex Projects: A Case Study Using System Dynamics," System Dynamics Review Vol. 17, No.3, (2001): 259.

55 A.G., Rodrigues, and T.M. Williams, "System Dynamics in Project Management: Assessing the Impacts of Client Behavior on Project Performance," The Journal of Operational Research Society 49 (1998): 3.

56 James M. Lyneis, Kenneth G. Cooper, and Sharon A. Els, "Strategic Mangement of Complex Projects: A Case Study Using System Dynamics," System Dynamics Review Vol. 17, No.3, (2001): 237.

57 A.G., Rodrigues, and T.M. Williams, "System Dynamics in Project Management: Assessing the Impacts of Client Behavior on Project Performance," The Journal of Operational Research Society 49 (1998): 3.

58 Tarek, K. Abdel-Hamid and Stuart E. Madnick, *Software Project Dynamics: An Integrated Approach* (New Jersey: Prentice Hall, 1991), cited in A.G., Rodrigues, and T.M. Williams, "System Dynamics in Project Management: Assessing the Impacts of Client Behavior on Project Performance," The Journal of Operational Research Society 49 (1998): 3.

59 C. Lin and R. Levary, "Computer-aided software development process design," *IEEE Trans Software Engng* 15(9): 1025-1037, cited in A.G., Rodrigues, and T.M. Williams, "System Dynamics in Project Management: Assessing the Impacts of Client Behavior on Project Performance," The Journal of Operational Research Society 49 (1998): 3.

Technology Adoption (TA) in a specific organization is a highly complex issue in which many key players are involved. The causal and complex relationships among those players determine the behavior of that organization. However, understanding this behavior and generating a technology adoption policy is a very difficult problem to solve by classical methods. The SD modeling approach offers opportunity to simulate the technology adoption process while including the key variables and running the simulation in a timely manner. This appears to be a reasonable approach in determining the existing behavior within an organization. One of the premises, on which the SD philosophy is based, is as follows[60].

> The behavior (or time history) of an organizational entity is principally caused by its structure. The structure includes not only the physical aspects, but more importantly the policies and procedures, both tangible and intangible, that dominate decision-making in the organizational entity.

Although the technical features of training support devices play an important role in the aviation training environment, the organizations' structures and the different approaches towards using those systems may generate a variety of technology adoption trends for similar technologies. The resistance and/or favorable perception of the individuals and the organizations towards the adoption of the technologies are the two most important factors in the diffusion of innovation.

The high cost of aviation training and the complex operational environment force militaries to improve their own methods and to apply specifically-tailored practices in their training to sustain their competitiveness. Therefore, the greatest challenge for any military using FTSET is to increase the effectiveness of training without significantly increasing the cost of this training. This is an active area of research in the study of the SD philosophy.

In order to develop our AP computer model and to conduct related experiments, the *Stella Modeling and Simulation Platform* was employed. The objective of the model is to gain insight into this complex system. The feedback perspective of the SD is also utilized during the modeling process.

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60 Tarek, K. Abdel-Hamid and Stuart E. Madnick, Software Project Dynamics: An Integrated Approach (New Jersey: Prentice Hall, 1991), 9.

B. EXISTING ADOPTION MODELS IN SYSTEMS DYNAMICS

Among the existing adoption models in the literature, two models are noteworthy in terms of their varying focus. The first is based on a technological innovation while the second focuses on the user of a technological innovation[61]. These models are referred to as source-centered and user-centered models[62]. Each approach has an impact on the other, and may utilize results from the other, especially, when the matter is technology adoption. The source-centered and user-centered model approaches may shed light on the TUAA study and form the basis of an appropriate technology adoption model. Innovation adoption process models, using these two approaches, were found in the literature and are depicted in Figure 5.

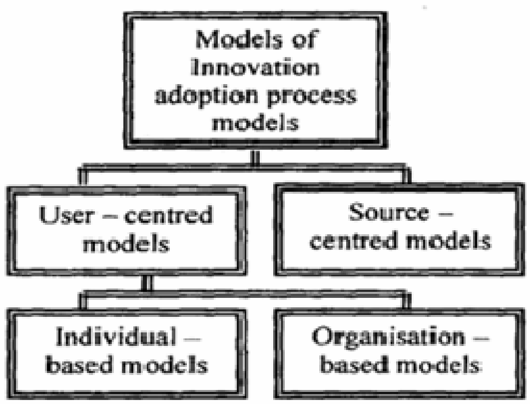

Figure 5. Innovation Adoption Process Models[63]

1. The Association of FTSET AP and Source-Centered Models

Source-centered models view adoption of a new technology from the perspective of the developer and take into account the following stages: evaluation, marketing, and dissemination[64]. These stages may explain FTSET improvement trends and the innovations made in this area. The FTSET industry is mostly associated with state-of-the-art technologies because related products are mostly tailored according to the unique needs of a customer. These are mostly software-related products.

61 Mohamed Gamal Aboelmaged, "Researching Information Technology Adoption Process in Higher Education Institutions: A Rational for Applying Individual-based Models," IEEE (2000): 385.

62 Ibid.

63 Ibid.

64 Ibid.

Due to increased FTSET use and greater over-time demand, more commercial-of-the-shelf (COTS) products have been introduced into the market. COTS products for FTSET are mostly hardware, such as motion platforms, vibration platforms, projector systems, cooling systems, etc. It is possible to find COTS software products like simple computer-based trainers in the FTSET market; however, their certification has been a challenging issue, particularly since both types of products may be used in official flight training curriculums at different stages. A system may be certified if it can be shown to have attributes that meet certain recommended values, its performance meets acceptable limits on certain defined criteria or it is shown that defined analyses or test methods have been applied to the design[65]. Despite a variety of discussions, simulators that offer very high fidelity do not represent a serious problem for certification, but the problem becomes more difficult as training devices depart from being faithful replicas of the aircraft and aircraft systems they represent.[66]

The FTSET industry should generate solutions based on both military and civil customer training needs and specific applications. Accordingly, acquisition professionals should be capable of understanding industry's solutions and the end-users' mission needs. Absent these two requirements, the adoption profile of an acquired technology will not meet expectations. Moreover, instead of establishing cost-effective training, resources would be consumed inefficiently.

Marketing and advertising are two very significant activities in the FTSET industry and provide for greater customer awareness and higher sales leading to better innovation adoption. This is explained via one of Roger's five technology adoption attributes, trialability[67]. This attribute is summarized by; the following statement: the

65 John R. Wilson: "The Gains from Certification are in the Process," in *Human Factors in Certification* ed. John A. Wise & V. David Hopkin (Mahwah, New Jersey and London: Lawrence Erlbaum Associates, Publishers, 2000), 30.

66 Richard S. Gibson, "Certification of Training," in *Human Factors in Certification* (Mahwah, New Jersey and London: Lawrence Erlbaum Associates, Publishers, 2000), 156.

67 Trialibility is the degree to which an innovation may be experimented with on a limited basis. The personal trying-out of an innovation is a way to give meaning to an innovation, to find out how it works under one's own conditions. This trial is a means to dispel uncertainty about the new idea. Rogers suggests that the trialibility of an innovation, as perceived by the members of a social system, is positively related to its rate of adoption.

earlier the involvement of an end user, the better a product's design and the faster its technology adoption.

Marketing and advertising techniques are also accepted as a part of source-centered adoption models. Market pattern forecasting for a new FTSET, its expected life cycle, and its expected technology adoption level are determinants in estimating the amount of capital investment and the correct timing required for the introduction of a new product. Technological differentiation of a product is demonstrated in the market growth phase. In this phase, advertising serves to stress the relative merits of differing products, and assists in determining the most adoptable design and to enhance product utility.[68]

In this context; while predicting the future state of science and technology, exploratory technological forecasting techniques may be used[69] and one of these techniques is explained as follows:[70]

> Formal trend extrapolation to either a straight-line fit or an S-shaped expectation …Using statistical "best fit" procedures, a growth-of-technology line is drawn through the data points and extended into the future. An assumption of technology saturation effects produces the biological growth pattern with its S-shaped curves; an assumption of no saturation leads merely to longer straight lines

This technique is employed in the Technology Improvement and Acquisition Sector of the FTSET AP model while modeling a source-centered perspective for FTSET AP.

2. The Association of FTSET AP and User-Centered Models

User-centered models help gain insight into understanding human-associated innovation adoption behavior. These models are not only related to individual users but also any organization which might be exposed to a new idea, innovation, or new technology. In this research, both individual- and organization-based models are employed in addition to source-centered models.

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[68] Jay W. Forrester, "Advertising: A Problem in Industrial Dynamics," in *Managerial Applications of Systems Dynamics*, ed. Edward B. Roberts (MIT Press, 1981), 201.

[69] Edward B. Roberts, "Exploratory and Normative Technological Forecasting," in *Managerial Applications of Systems Dynamics*, ed. Edward B. Roberts (MIT Press, 1981), 375.

[70] Ibid.

In the modeling process, we make use of the Bass Diffusion Model[71], Replacement Purchases Model[72], Repeat Purchases Model[73], and Logistics Model of Innovation Diffusion,[74] with some alterations to fit our case. By using these models, we can represent the human-associated variables in our model, such as attraction, transfer of training, perceived usefulness of the technology, etc.

The Bass Diffusion Model was developed by Frank Bass (1969) and it overcomes the startup problem[75] of logistic and the other simple growth models[76]. How one is first made aware of or exposed to an innovation was also recognized and included as a component in a knowledge stage defined by Rogers[77]. The Bass Model, however, is not capable of explaining some common features of repeat or replacement purchases. This is why the Bass Diffusion Model does not adequately model situations where a product is consumed, discarded, or upgraded, all of which lead to repeat purchases. Further, this explains why this model is often described as a first-purchase model.[78] To adapt this model to the FTSET AP of the TUAA, we utilize Replacement and Repeat Purchases Models and also revise the Bass Model to incorporate growth in the size of technology support potential[79].

In the FTSET AP model, we consider that FTSET is developed and provided by the industry and acquired, adopted, and discarded by the end-user throughout the process.

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71 John D. Sterman, Business Dynamics: Systems Thinking and Modeling for a Complex World (New York: Irwin McGraw-Hill, 2000), 332.

72 Ibid.343.

73 Ibid.344.

74 Ibid.325.

75 Start up problem: In the logistic, zero is an equilibrium: the logistic model can not explain the genesis of the initial adopters where Bass Diffusion Model solves the problem by assuming that potential adopters become aware of the innovation through external information sources such as word of mouth (social exposure and imitation) John D. Sterman, Business Dynamics: Systems Thinking and Modeling for a Complex World (New York: Irwin McGraw-Hill, 2000, 334.

76 John D. Sterman, Business Dynamics: Systems Thinking and Modeling for a Complex World (New York: Irwin McGraw-Hill, 2000), 332.

77 Mohamed Gamal Aboelmaged, “Researching Information Technology Adoption Process in Higher Education Institutions: A Rational for Applying individual-based Models,” IEEE (2000): 385.

78 John D. Sterman, Business Dynamics: Systems Thinking and Modeling for a Complex World (New York: Irwin McGraw-Hill, 2000), 342.

79 Ibid.336.

However, unlike the Replacement Purchases Model, discarded technology is not allowed to return into the system as an available potential to be captured since inflow has already been considered into our model, thus feeding Usable Technology pool from Acquirable Technology pool. The potential, referred to as a percentage of support, should be recognized as a partial substitute for actual flight training hours. The discarded portion (the result of Capability Discard Rate), for example, is referred to as a percentage of support and is the result of technology obsolescence. The processed variable in the model is not the technology itself, but the capability resulting from development, acquisition, adoption and discarding of FTSET.

The FTSET users' population is not included in the modeling process as an input. Estimations made on individual preferences are represented by percentages in the model cumulatively since the organizational behavior of technology adoption is of primary interest over each individual's preference. In brief, organizational behavior of technology adoption should be considered as the cumulative total of all individuals' perceptions, TUAA' s institutional attitude towards the use of FTSET, and the causal relations among them. Independent variables (the concept will be also discussed in Section III.B), such as the effect of actual missions, have been included, but the number of those variables has been kept to a minimum in the FTSET AP model.

a. Individual-Based Model

Roger's five-stage model, together with his five attributes of technology adoption (already discussed in Section I.E.2.), and other individual-based models shed light on our approach to modeling technology adoption.

Roger's five-stage innovation adoption process has been mainly considered in the context of an individual-based model. It is one of the most widely discussed processes (Pagani 2004, Aboelmaged 2000, Rogers 1995) in the technology adoption literature and can be described as follows:[80]

> <u>Knowledge;</u> is characterized by the individual's exposure to the existence of the innovation and some understanding of how it functions.

[80] Mohamed Gamal Aboelmaged, "Researching Information Technology Adoption Process in Higher Education Institutions: A Rational for Applying individual-based Models," IEEE (2000): 385.

Persuasion; is the formation of favorable and unfavorable attitudes toward the innovation.

Decision; is the pursuit of the activities that lead to a choice to adopt or reject the innovation.

Implementation; is putting the innovation to use.

Confirmation; is when individuals seek reinforcement subsequent to their decision and initial use of an innovation

FTSET awareness occurs right after the initial use of the technology and is attributed as knowledge and persuasion stages in the FTSET AP model. Initial FTSET users are the first category of adopters and are defined as innovators (Pagani 2004, Rogers 1995). In our case, these are the TUAA School examiner and instructor pilots together with the pilots that have had a prior chance to practice on FTSET at least once. They are considered the "customers" and are the first to experience either favorable or unfavorable technology awareness.

In Havelock,[81] the first stage is considered awareness. In our model, Roger's decision and implementation stages are represented by appropriate use of the training environment and customization. The user, having favorable awareness towards FTSET, would pursue opportunities for more expertise and technology customizing. This behavior can also be explained by the "perceived usefulness" which was described in discussing the Technology Acceptance Model (TAM) earlier in section I.E.2. This is a persuasion stage. Once use of technology and awareness increases, appropriate use of training and transfer of training increases. These are the implementation and confirmation stages, respectively, and have a favorable impact on technology customization and on the technology adoption rate.

[81] G. Havelock, "The Change Agent's Guide to Innovation in Education," Educational Technology Publications (1973), cited in Mohamed Gamal Aboelmaged: *Researching Information Technology Adoption Process in Higher Education Institutions: A Rational for Applying Individual-Based Models* (Management Science Department: Lancaster University Management School, 2000), 385.

b. Organization-Based Model

The four step model[82] used by Hage and Aiken, is helpful in explaining our FTSET AP model from an organizational point of view. This four step model is described as follows:

> <u>Evaluation;</u> is considering the need for change. An explicit initial attempt to allow potential adopters to take a broader view of whether the innovation is necessary, as well as to consider the setting in which the proposed innovation will operate.
>
> <u>Initiation;</u> is involving the choice of a solution and the search for resources.
>
> <u>Implementation;</u> is when the organization attempts to actually begin using the innovation.
>
> <u>Routinization;</u> is when the entire organization undertakes efforts to stabilize an innovation that is currently being used

In our model; the idea, regarding FTSET acquisition and the first persuasive action towards encouraging system acquisition is considered the evaluation phase. It is also appropriate to include TUAA's point of view in the model as an organization-based evaluation step. In our model, this step is represented by Minimum Target of Use of FTSET. Required Need and Fund Availability Ratio, determined according to Technology Gap, are included as variables in our model. These variables are considered within the definition of the initiation step. FTSET customization, nominal technology adoption goal, and the execution of minimum target of technology use principle represent the implementation and the routinization steps of the Hage and Aiken model[83].

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[82] J. Hage and M. Aiken, "Social Change in Complex Organizations," Random House (1970), cited in Mohamed Gamal Aboelmaged: *Researching Information Technology Adoption Process in Higher Education Institutions: A Rational for Applying Individual-Based Models* (Management Science Department: Lancaster University Management School, 2000), 386.

83 Ibid.

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III. THE PROBLEM AND THE DYNAMIC HYPOTHESIS

A. THE DYNAMIC HYPOTHESIS

1. Formulating the Dynamic Hypothesis

In the late 1970s, the idea of using FTSET in helicopter flight training was quite new for TUAA, and studies directed towards its use started in the early 1980s. The helicopter FS studied in this project was installed in 1989. In the first few years of employment, this system was used mostly for pilot candidate flight training. Since then, system use has expanded to different phases of the TUAA flight training curricula,such as instructor pilot instrument and emergency procedures training, cockpit resource management (CRM) training, test pilot procedure training, instrument flight check-ride, etc. The studied helicopter FS constitute the part of a simulation-based training system in the TUAA. These helicopter FS cabins are replicas of UH-1 helicopters and are seated over a six-degree-of-freedom motion platform.

Helicopter FS use and its adoption in the TUAA materialized over the past 17 years and experienced a substantial increase in usage in the late 1990s. However, over time this growth stagnated. The technology adoption profile for our case has the S-shaped growth shown in Figure 3. It is the S-shaped growth experienced by many technology adoption processes. In this study, we examine the TUAA FTSET AP in order to understand the historical trend and to extrapolate the future behavior of FTSET technology.

By examining Figure 6, we note that lower FTSET support rates prevailed until 1997, followed by higher rates through 2001. Further, the last six years' (after 2001) average is almost three times greater than the first eight years' (10.4% average for 1990-1997, and 27.8% average for 2001-2006). Despite the last six years' higher support rates, we observe a plateau in growth rate and growth stagnation between 2001 and 2006. Any further increase in the support rates is not expected for the upcoming years because the last six years' trend demonstrates a saturation in the use of FTSET (Figure 6).

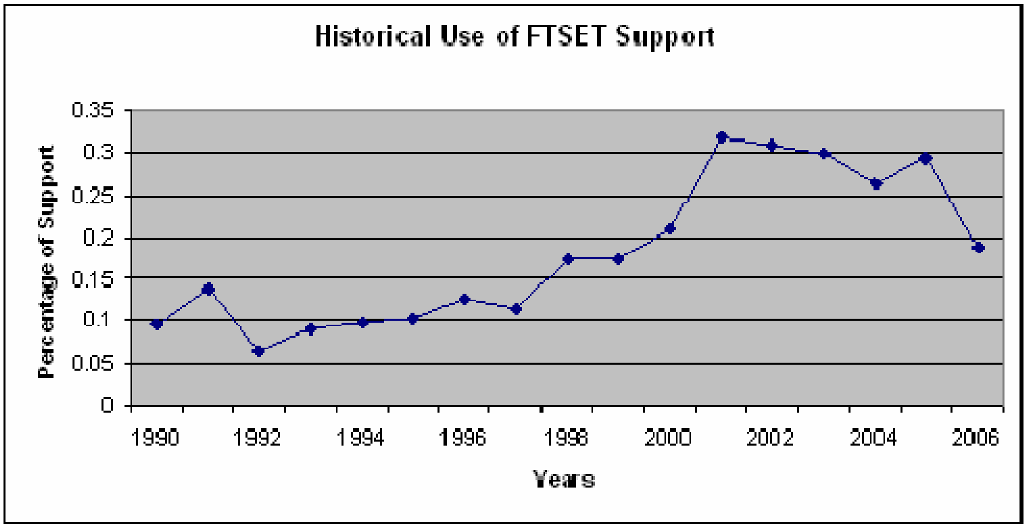

Figure 6. TUAA Historical Use of the FTSET Support

Based on interviews with TUAA field and instructor pilots, as well as helicopter FS technical support personnel, and according to survey responses (Lafçı, 2005), we identified several factors that may have an effect on the use of TUAA FTSET. These interviews and surveys suggest that the following areas are significant[84] for us to incorporate into the FTSET AP model:

- Technological features of the system
- Training support capability of the system
- System's aging and life cycle
- System's ease of use
- System's usefulness
- FTSET caused physical problems
- Personal attitude towards FTSET
- Organizational attitude towards FTSET
- Official and unofficial culture towards FTSET
- Different knowledge and awareness level of each end-user and organization

[84] Aydın Lafçı , "The Importance of Simulator Usage in TUAA Flight Combat Readiness Training and determining the optimum usage rates" (M.S. thesis, Turkish Military Academy Defense Sciences Institute of Technology Management, 2005).

- Effective communication
- Management of technological capability and technical expertise
- Mission and actual flight intensity level

Noting these observations and the existing adoption models (already discussed in Sections; I.E.1, I.E.2, and II.B.2); together with the TUAA Historical Use of the FTSET Support as depicted in Figure 6, we find the TUAA FTSET AP is similar to other technology adoption patterns. Regarding the S-shaped growth observed in this case, we hypothesize that:

- The lower adoption rate prior to 1997 stemmed from an organizational culture that was uncomfortable with the use of FTSET, both at the individual and organization level.
- The acceleration of adoption rate between 1997 and 2001 originated from organizational change in favor of FTSET usage and increasing expertise in the FTSET management.
- The leveling off of the adoption rate in recent years has resulted from the system's limited technical capability and its sole support for one type of helicopter.

2. Key Factors

a. Organizational Culture

Although transferring actual flights to a SF environment became an integral part of commercial airline operations in the 1960s, in many countries the role of FS has only really gained acceptance for military training during the last decade[85]. Therefore, we posit that the use of FTSET as a substitute for actual flights was not a part of the organizational culture in the TUAA during the early 1980s. Similarly, the US Army Aviation training community did not also acknowledge develop training efficiency prior to the mid 1990s[86].

We assume that this lack of foundation towards the use of technology in an organization results in less technology awareness level among its members. These factors have an impact on an individual's behavior and their attitudes toward the

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85 Ray L. Page, "Brief History of Flight Simulation", 2.

86 John E. Stewart III, John A. Dohme, and Robert T. Nullmeyer, "Optimizing Simulator-Aircraft Mix for US Army Initial Entry Rotary Wing Training," Technical Report 1092 (March 1999): 7.

respective technology. Even if an effective communication program, articulating the benefits of such a technology could be maintained in an organization, each individual's knowledge and/or awareness level might differ regarding the new technologies. If too much variance exists among the individuals' knowledge level in an organization, the technology adoption process might be slower than expected. In our case, we assume that TUAA School examiner and instructor pilots, and/or the pilots who had exposure to FTSET in their previous personal experiences (an opportunity to perform flight training in FS before) were more knowledgeable[87] than other members of the TUAA and as innovators[88] (See Pagani 2004) they introduced the idea of using FTSET in training drills.

It is generally expected that the use of technology increases the awareness level and thus the adoption probability of a given technology (See Al-Gahtani 2003). During the slower technology adoption part of the TUAA FTSET, the problem of lower usage level may stem from personal and organizational lack of knowledge regarding FTSET. We suggest that the perceived usefulness[89] of the TUAA FTSET early on was not as effective as in the latter period for the end-users. As night vision goggle (NVG) and IFR flights have accelerated over time, the use of FTSET has been seen as an opportunity by pilots and the TUAA community. It has also been observed that FTSET provides an appropriate flight training environment and an increase in the effectivity of learning. These organizational changes have resulted in greater inclusion of FTSET into the training system.

[87] Knowledge is the first stage in individual based innovation adoption model (see section II.B.2a.).

[88] Roger's category of adopters' model referenced in Margherita Pagani, "Determinants of Adoption of Third Generation Mobile Multimedia Services," Journal of Interactive Marketing 18 (2004): 57.)

89 "The perceived usefulness" is defined as the degree to which a person believes that using that particular system would enhance his or her job performance while "the perceived ease of use" is defined as the degree to which a person believes that using a particular system would be free of effort.

b. Expertise and System's Reliability

Generally, complex and highly technical systems like FS exhibit similar failure patterns through their life cycles and aging processes[90] as depicted in Figure 7. We expect that the reliability ratio of the TUAA FTSET should be similar to these failure patterns. Figure 7 shows a typical failure distribution pattern for a generic system. As shown in Figure 8, the TUAA FTSET system reliability and operational expertise have risen to a recognizable level over time. This in turn has made the system more inherently available[91].(discussed in Section IV.A.3). As shown in Figure 8, lower inherent system availability converts to higher availability over time. It is obvious that greater learning has been experienced through the FTSET's last years of service (2001-2006).

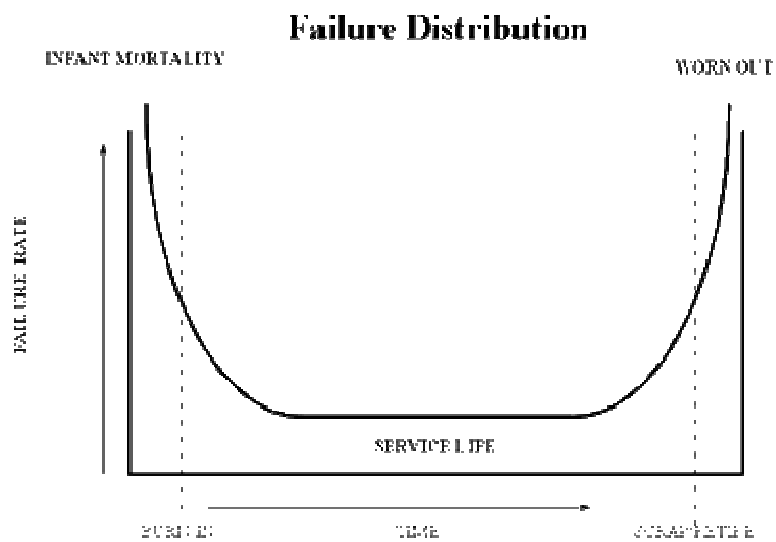

Figure 7. Logistics "Bathtub Curve": Failure Distribution over System's Life Cycle[92]

[90] Leroy Gill, Class Handout, LOGM 569, Life Cycle Cost and Reliability, Dept. of Systems & Engineering Management, Air Force Institute of Technology, Wright Patterson AFB OH 1987, cited in Christopher D. Purvis, "Estimating C-17 Operating and Support Costs: Development of a System Dynamics Model" (M.S. thesis, Air Force Institute of Technology, March 2001).

[91] Probability that a system when used under stated conditions in an ideal support environment will operate satisfactorily at any time.

[92] Naval Postgraduate School / Graduate School of Business Public and Policy - GB4450MN4470: Systems Management Lecture Slides; 8-22 Logistics Test & Evaluation; Strategy Formulation and Implementation Phases.ppt., 11/14/2006.

Regarding the stagnation trend in FTSET usage between the years 2001 and 2006, previously depicted in Figure 6, we note that a system's aging and life cycle should not be a concern since inherent availability rates have remained around 80-90% between these years (Figure 8).

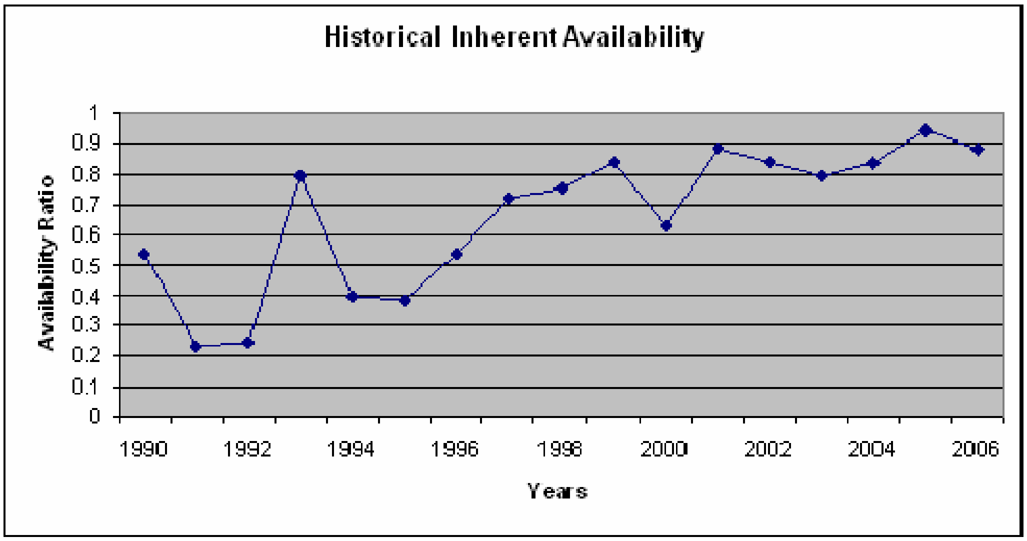

Figure 8. TUAA FTSET Historical Inherent Availability over Time

c. Current FTSET Technical Aspects

The technical support capability of TUAA FTSET may constrain the variety of training drills that can be executed on FS. Lower resolution levels, the limited visual data base of the current FTSET and its sole support for one type of helicopter are the three greatest constraints on higher rates of use of the FTSET. These constraints may limit training unfavorably, causing saturation in the last six years' usage as depicted in Figure 6. It is highly probable that the current FTSET could provide less training support qualitatively comparing to Level C and D FS. As mentioned in Section I.A.(p.8), the current FTSET meets FAA AC 120-63 Helicopter Simulator Qualification Document Level B criteria (Demir, May 2001).

An additional issue is that the support provided in the current FTSET pertains only to one type of helicopter since it is a "devoted system"[93]. However, IFR

[93] Devoted System: Flight Simulators, having no convertible cockpits for other types of aircrafts, are designed to support one type of aircraft's specific training drills.

procedures are mostly general and can still be executed in the current FTSET without a requirement for different FS

B. MODEL BOUNDARY

Having examined the factors that affect our initial dynamic hypothesis, we are able to draw our model boundary and determine the key variables that should be included into our model structure. Here, the idea is to capture the important feedback loops rather than a lot of detail in the specification of the model variables.[94].

Having examined the associated issues, we suggest the variables that should be included in the three different, but interconnected; sets of processes developed in this study of the FTSET AP model. They are Technology Improvement and Acquisition, Technology Adoption, and Technology Discarding. Initially, we thought the exogenous variables listed in Table 1 might have an impact on these processes, similar to that of the endogenous variables[95]. Two reasons convinced us to discount them from our model boundary; information scarcity, and model complexity. Despite an exhaustive review of the literature, we could not get adequate information to include them into the FTSET AP model. Next, including them would have resulted a more complex and confusing modeling process.

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[94] John D. Sterman, Business Dynamics: Systems Thinking and Modeling for a Complex World (New York: Irwin McGraw-Hill, 2000), 96.

[95] The two main types of variables creating causal effect inside and outside the boundary are called “endogenous” and “exogenous”. Endogenous variable explains the dynamics of a system through the interaction of the variables represented in the model while exogenous defines the other variables and the assumptions outside the boundary (see Sterman 2000).

Endogenous	Exogenous
Industry’s Target of Support	Quantity and Quality of Human Resource
Industry's Maximum Support Potential	Quality of Instruction Methods
Technology Improvement Trend	Quality of Flight Training Curriculums
Industry Improvement Rate	Other Helicopter and Simulator Types in Use
Industry Improvement Ratio	Impact of Other Simulators Usage Levels
Improvement Rate	Individual Based FS Usage Ratios
Acquired Technology Support	Aging of helicopter FS
Technology Acquisition Rate	Delays in the Processes
Technology Gap	Types of Modifications and Acquisitions
Expected Technology Obsolescence Rate	
Required Need	
Required Fund Level	
Funding Rate	
Reserved Fund Level	
Fund Availabillity Ratio	
Fund Availability Ratio	
Acquisition Rate	
Usable Technology	
Technology Used	
Net Contribution Rate	
Favorable Technology Awareness	
Favorable Transfer of Training	
Effective Learning	
Cumulative Transfer Effectiveness Ratio	
Appropriate Use of Training Environment	
Minimum Target of Use	
Mission Intensity Level	
Effect of Customization	
Nominal Adoption Rate	
Technology Adoption Rate	
Ssytem Inherent Availability	
Logistics Cycle Time Differential	
Technology Obsolescence Rate	
Expected Technology Obsolescence Rate	
Capability Discard Rate	

Table 1. FTSET Adoption Process Model Boundary Chart

IV. MODEL STRUCTURE

A. STOCKS AND FLOWS

The FTSET AP model structure is depicted in Appendix A. It is divided into three sectors: 1) Technology Improvement and Acquisition, 2) Technology Adoption, and 3) Technology Discarding.

- The Technology Improvement and Acquisition sector is a simple structure which includes helicopter flight simulator technology improvement and related technology acquisition processes.
- The Technology Adoption sector captures how, and the level at which, the FTSET is adopted. In this sector; the main themes are technology awareness, transfer of training, transfer effectiveness, minimum target of use, customization, and adoption. The variables in this sector are mostly associated with human behavior and processes while the other sectors are mainly concerned with mission- and cost/benefit -related issues.
- The Technology Discarding sector captures how a simulator technology is discarded based on technology obsolescence and expected acquisitions. The related variables are associated with how much the current system meets maintainability criteria and performance expectations compared to the FTSET Industry's cutting edge systems.

1. Sector 1: Technology Improvement and Acquisition

In this sector, there are two main sections: Technology Improvement and Technology Acquisition respectively. The Technology Improvement section is comprised of the following subfactors: Industry Target of Support, Industry Maximum Support Potential, Industry Improvement Rate, Technology Improvement Trend, Industry Improvement Ratio, Improvement Rate, and Acquirable Technology. The Technology Improvement and Acquisition Sector and its subfactors are demonstrated in Figure 9.

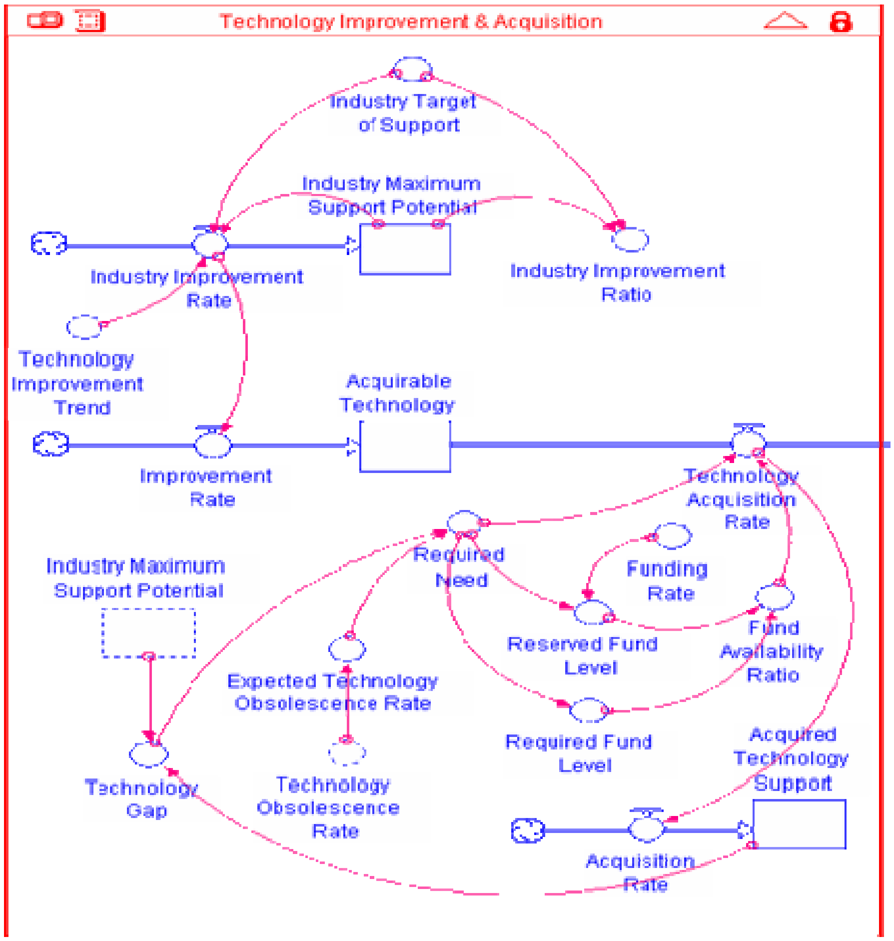

Figure 9. FTSET AP Model Technology Improvement and Acquisition Sector

Each subfactor in this sector is discussed in relation to the FTSET AP and is described as follows:

a. Industry Target of Support: This subfactor represents industry's recent synthetic environment (SE) flight goal, as a percentage of support for military helicopter flight training. The industry claims that training sequences will employ SE, which will replace up to 75% of required flight training hours96. In our model, we take the industry's target and use 75%.for target of support. Several factors come into play in determining this value which may cause the industry to revise its goal. For example, introduction of more beneficial training methods and technologies might change the

96 Tim Mahon, "Sims with Service," Training and Simulation Journal (2006), http://www.tsjonline.com/story.php?F=27865576US (19 June 2006).

course of the actions and environment for FTSET stakeholders. A specific example is the key milestone in the development of Helicopter Collective Training Systems (HCTS).

HCTS is the demonstration of a Live to Virtual Interface which may not only result in the transfer of the training flights but also actual mission flights into the SE. This is the first opportunity for the pilots to engage real targets using the FS[97] systems and designate these targets to the actual aircrafts flying over a mission zone. This new development might totally change the direction of simulator-aircraft correct mix discussions and further shape the FTSET Industry since the use of FS in actual missions will be an issue in the near future.

b. Industry Maximum Support Potential: This subfactor represents the capability which could be provided to the end-user via latest technology. It is determined by the Industry Improvement Rate. Initially, we assumed military helicopter FS support was 21% of the required training flights per pilot in 1990. The value is determined by Industry Improvement Rate and explains the degree to which the FTSET Industry is capable of supporting military helicopter flight training per pilot today.

FS support for basic pilot training curriculums in TUAA School has varied between 21-25% since 1990. For US Army Aviation School, this rate is 21.7%[98]. The helicopter FS, presently in use for two of the aviation schools, are complex and expensive. They are representative of military helicopter FTSET of the 1970s[99] and mid 1980s.

c. Industry Improvement Rate: The magnitude of this rate is determined by the gap between Industry Target of Support and its Maximum Support Potential. Continuous improvement and shorter development cycles associated with computer-related technologies are drivers of this rate in the FTSET Industry. This gap is assumed to be filled in a period determined by the Technology Improvement Trend, which is

97 Tim Mahon, "Sims with Service," Training and Simulation Journal (2006), http://www.tsjonline.com/story.php?F=27865576US (19 June 2006).

98 The FS XXI Training Implementation Plan Presentations (26 December 2001): "The Common Core" is used for initial helicopter training for the beginners while "The Advanced Track" is mentioned for advanced helicopter training in the FS XXI Training Implementation Plan Presentations.

99 John E. Stewart II et al., eds., "Assessing the Effectiveness of a Low-Cost Simulator for Instrument Training for the TH-67 Helicopter," Research Report 1780 (December 2001): v.

represented by the factor of “0.1” (10% a year technology gap closing speed) in Equation (0.1).

$$\text{Industry Improvement Rate} = \left(\text{Target Support} - \text{Industry's Maximum Potential}\right) \times .1 \qquad (0.1)$$

d. Technology Improvement Trend: This subfactor is a constant in our model. It shows the FTSET Industry intention of closing the technology gap between Industry Target of Support (objective) and Industry Maximum Support Potential (actual) over a certain period of time. The default value is assumed to be 10% a year, which is a reasonable value to allow the FTSET Industry to close this gap.

Although the FTSET Industry has not claimed that a cutting-edge FTSET could support military helicopter flight training drills by “100% SF” yet, at least a decade ago, civil flight schools accomplished transferring most of the flight training hours to FS. There are some military applications of FS intensive training for fixed-wing pilots. For instance; newly winged pilots at the 201st Airlift Squadron are sent off to Boeing training facilities in Miami, FL or Seattle, WA to complete a six-week training curriculum. As with airline pilot curricula, no time is designated for actual aircraft flight[100]. This training objective could be achieved via cutting-edge technologies such as Level D simulators since they require no aircraft flight time for transition training with an approved training program[101]. Today, the new goal might be to reach 75% percent simulator flight in military helicopter flight training[102].

e. Industry Improvement Ratio: This subfactor represents the degree to which the FTSET Industry goal has been achieved versus the industry’s claimed goal. This can be expressed by Equation (0.2) as follows:

$$\text{Industry Improvement Ratio} = \frac{\text{Industry's Maximum Potential}}{\text{Target Support}} \qquad (0.2)$$

100 Jay S. Vignola, “A Study of the Potential Cost Savings Associated with Implementing Airline Pilot Training Curricula into the Future P-8 MMA Fleet Replacement Squadron” (MBA thesis, Naval Postgraduate School, 2006)

101 Archie E. Dillard, “Validation of Advanced Flight Simulators for Operational Evaluation and Training Programs,” presented as a briefing, 12 October 2002.

102 Tim Mahon, “Sims with Service,” Training and Simulation Journal (2006), http://www.tsjonline.com/story.php?F=27865576US (19 June 2006)

f. Improvement Rate: This subfactor represents the FTSET Industry improvement in terms of helicopter flight training support percentage and takes the same value as the Industry Improvement Rate. It is used in computing the Acquirable Technology pool discussed below.

g. Acquirable Technology (AT): This subfactor is a technological opportunity pool increased by the Improvement Rate. Current FTSET could be updated and its support capability could be enhanced by acquiring newer technology from the FTSET Industry. The AT pool represents those opportunities and technological solutions offered by the FTSET Industry. The AT is represented as a percentage of SF training support. The Industry Maximum Support Potential less all the acquired capability between 1990 and 2006 equals the AT. This value is initially 21% which is assumed as military helicopter FTSET support per pilot in 1990.

The Technology Acquisition section is comprised of the following subfactors: Technology Gap, Expected Technology Obsolescence Rate, Required Need, Fund Availability Ratio (result of Required Fund Level, Reserved Fund Level, and Funding Rate), and Technology Acquisition Rate. Each of these subfactors is discussed in relation to the FTSET AP, and is described as follows:

a. Technology Gap: This subfactor represents the difference between the Industry Maximum Support Potential and its Acquired Technology. It represents the ideal technology objective to be captured. This gap should be filled via acquisitions since the intention is to keep the current system updated and ready to meet training support demands.

b. Expected Technology Obsolescence Rate: This subfactor is determined according to the Technology Obsolescence Rate (TOR). Here, we use a smoothing function in Equation (0.3) to make obsolete technology cycle estimates. The smoothing period is five years. The last five years' smoothed average is accepted as an annual Expected Technology Obsolescence Rate, and in turn, becomes one of the two determinants of Required Need.

$$smthn\left(\text{Technology Obsolescence Rate, 5, 1}\right) \tag{0.3}$$

c. Required Need: This subfactor, is determined from the Expected Technology Obsolescence Rate and the Technology Gap. Required Need represents the amount of support required to meet improved training criteria and mission accomplishment requirements. Without meeting Required Need, efficiency of training support would decay since the TOR continuously dominates the Discard Rate.

d. Required Fund Level: This subfactor is determined by the Required Need and is represented as a percentage vice a monetary value. In this study, our aim is to take this value and substitute it into the Reserved Fund Level/Required Fund Level ratio (also the Fund Availability Ratio), since this ratio can serve as a metric and a multiplier that has an impact on the Technology Acquisition Rate.

e. Reserved Fund Level: This fund level is determined by forecasting the Required Need and adjusted according to the Funding Rate. Here, the function takes the last ten year Required Need average and forecasts the annual Reserved Fund Level. An annual inflation rate of 5% is assumed in forecasting which is also expressed in the following Equation (0.4). Like in the Required Fund Level determination, our aim is not to evaluate the amount of funds that should be reserved, but to compare this percentage level to the Required Fund Level and to find a Fund Availability Ratio.

$$\mathit{frcst}\left(\text{Required Need, 10, 1, 1.05}\right) \times \text{Funding Rate} \tag{0.4}$$

f. Funding Rate: This subfactor represents all of the various funding conditions that may occur during the funding or budgeting processes. It determines with how much percentage the Reserved Fund Level can be funded. It signifies a measure of the Reserved Fund Level strength against the Required Fund Level. It is represented as a percentage and is assigned a default value of 90% in our model. Note that this rate might be varied to examine the sensitivity of the FTSET model in cases of reduced funding.

g. Fund Availability Ratio: This subfactor represents the relation between the Reserved Fund Level and the Required Fund Level as expressed in the following Equation (0.5). It is a multiplier used in computing the Technology Acquisition Rate and determines the magnitude of associated acquisitions.

$$\text{Fund Availability Ratio} = \frac{\text{Reserved Fund Level}}{\text{Required Fund Level}} \tag{0.5}$$

h. Technology Acquisition Rate: This subfactor is a combination of the Required Need and the Fund Availability Ratio. It determines the percentage of support that would be transferred from the Acquirable Technology to Usable Technology pool annually via technology acquisitions.

The purpose of these acquisitions is to enhance the FTSET features, and increase its maintainability and operability. Some specific application areas might be spare part inventory renewal, visual data base update, cooling system modification, uninterrupted power source (UPS) modification, power generator renewal, maintenance service outsourcing, etc. These acquisitions do not consist of huge modifications that might cause any change in the current FTSET category[103]. The category of FTSET and its main features should be tailored upfront according to requirements. Otherwise, it would be too costly to perform major updates and modifications, and is considered infeasible in the FTSET Industry. Two related attributes are mentioned in the following paragraphs.

First, technology level (mentioned earlier in section I.A, Army Aviation Software Growth of the Helicopters) of the helicopter and its associated technology cycle are important determinants in FTSET level selection process. They in turn determines FTSET life cycle. However, the rapid pace of technology evolution might create a life cycle mismatch in systems where the life cycle of the system elements is much shorter than the system of interest[104]. Recently, more rapid helicopter technology cycles have been experienced due to recent developments in software technology.

Second, helicopter FTSET is more costly than their associated helicopter types, but they could pay off their design and installation costs in a very short period (e.g. two to three years) if they are used efficiently. So, spending too much money for major

103 FS are both classified and certified by JAA and FAA as Level A through Level D simulators, where Level D is the highest level of certification.

104 Tom Herald, "Integration of Technology Assessment and Management Methodology for System Sustainment Determination," *International Council on Systems Engineering (INCOSE)* (11 Aug 2005),

<http://www.incose.org/practice/research/seanet_herald.aspx> (26 July 2006)

modifications in FTSET during the life cycle of a system might not pay off in this fast pacing industry. Dillard (2002) states this point as follows[105]:

> Modern technological development is out-pacing our ability to learn and apply innovations. New systems are forcing the obsolescence of existing systems in a very short time. The airline industry is saying that any new system must buy its way onto the flight deck with payback in a short time, generally three to five years.

i. Acquisition Rate: This subfactor is determined by the Technology Acquisition Rate and feeds into Acquired Technology Support pool.

j. Acquired Technology Support: This subfactor represents the amount of technology support that has been acquired cumulatively since installation of the first system. It is referred to as a training support percentage and is used for two purposes: determining the Technology Gap and the Minimum Target of Use.

[105] Archie E. Dillard, "Validation of Advanced Flight Simulators for Human-Factors Operational Evaluation and Training Programs," prepared for Foundations '02 V&V Workshop, John Hopkins University, Applied Physics Laboratory (2002): 25.

2. Sector 2: Technology Adoption

In this sector, there are four main sections: Technology Usage and Awareness, Transfer of Training, Customization, and Adoption respectively. The Technology Usage section is comprised of the following subfactors: Technology Used, Favorable Technology Awareness, and Net Contribution Rate. Technology Adoption Sector and its subfactors are demonstrated in Figure 10.

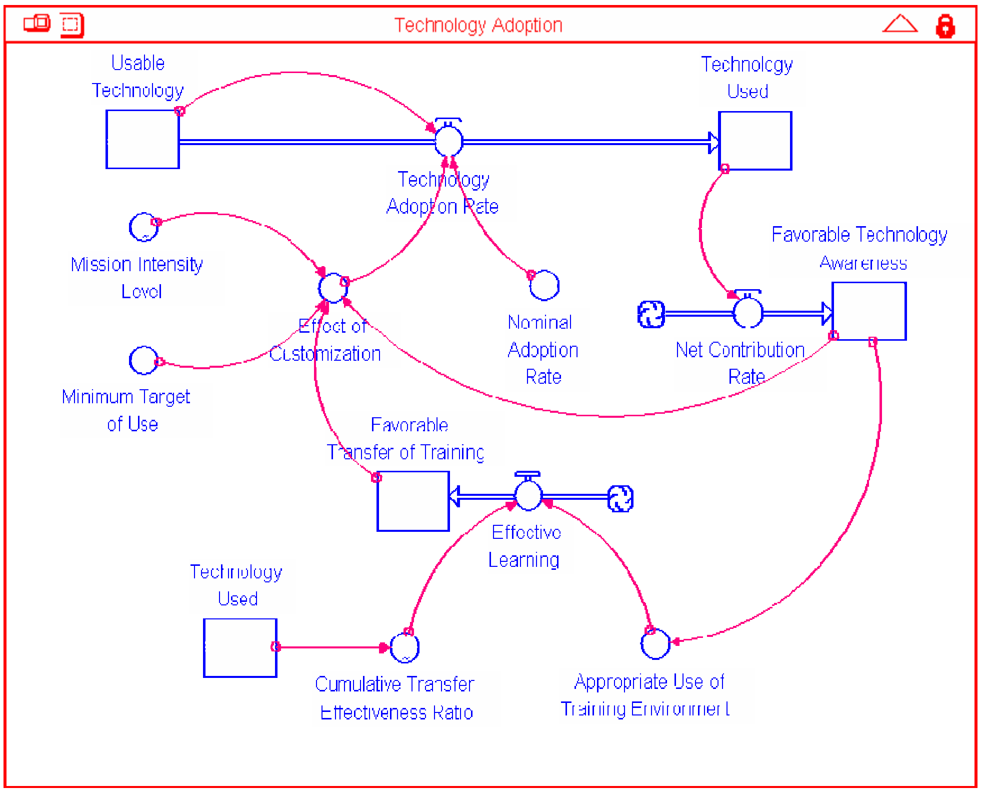

Figure 10. FTSET AP Model Technology Adoption Sector

Each subfactor in this sector is discussed in relation to the FTSET AP and is described as follows:

a. Technology Used: This subfactor represents the percentage of the FTSET in total flight training hours. The Technology Adoption Rate is used in computing the Technology Used pool. The Technology Used subfactor is our main metric since the level of use is accepted as one of the technology adoption attributes in the associated

literature[106] and it shows what the technology adoption pattern has occurred since the system started its service. Its initial value was set at 9.6%, based on the first year of actual FTSET use (previously depicted in Figure 6). Until the system entered into full service, it was mainly used in basic pilot and orientation training by the TUAA School examiner and instructor pilots.

b. Favorable Technology Awareness (FTA): In the TUAA, the first FTSET users (also referred to as innovators in Rogers' innovation adoption model)[107] were instructor pilots, examiners, and pilot candidates. They were the first individuals exposed to the existence of this innovation and some understanding of its function. This was the knowledge stage[108], also referred to as "awareness" by Havelock[109].

Knowledge has been accepted as an important variable that influences PU and PEU, with a positive or negative effect on attitude towards use of a new service[110]. We believe that FTA should be included in our model as a first stage right after the use of FTSET. Net Contribution Rate constitutes the link between Technology Used and FTA. FTA's magnitude is determined by the Technology Used and Net Contribution Rate. FTA also has an impact on two variables in the model: Effect of Customization and Appropriate Use of Training Environment. These subfactors explain both individual and organization based behaviors.

c. Net Contribution Rate: Net Contribution Rate comprises two factors: the Technology Used and the Technology Resistance respectively. Although the second factor is not represented in the model explicitly, its negative impact has already been

106 Said S. Al-Gahtani: "Computer Technology Adoption in Saudi Arabia: Correlates of Perceived Innovation Attributes," Information Technology for Development 10 (2003), 62.

107 Roger's category of adopters' model is referred in Margherita Pagani, "Determinants of Adoption of Third Generation Mobile Multimedia Services," Journal of Interactive Marketing 18 (2004): 57

108 E.M. Rogers, "Diffusion of Innovations," 4th ed. (1995): cited in, University of Twente Online http://www.tcw.utwente.nl/theorieenoverzicht/Levels%20of20theories/macro/Diffusion (12 October 2006)

109 G. Havelock, "The Change Agent's Guide to Innovation in Education," Educational Technology Publications (1973), cited in Mohamed Gamal Aboelmaged: Researching Information Technology Adoption Process in Higher Education Institutions: A Rational for Applying Individual-Based Models (Management Science Department: Lancaster University Management School, 2000), 385.

110 Margherita Pagani, "Determinants of Adoption of Third Generation Mobile Multimedia Services," Journal of Interactive Marketing 18 (2004): 52.

taken into account and subtracted from the Contribution Rate. The resultant rate is referred to as the Net Contribution Rate.

The Technology Resistance percentage applied in our case is 18% so that 82% of Technology Used becomes our Net Contribution Rate for Favorable Technology Awareness. The probable causes of this Technology Resistance in our case are discussed below.

1. Simulator Sickness: Physical problems caused by FTSET should be taken seriously for two reasons. First, almost everyone flying in the FS may possibly experience "simulator sickness" (SS) with differing discomfort levels. Second, the effect occurs during or after simulator flight may sometimes last for hours. In the literature, SS is defined as follows:

> Simulator sickness is a term used to describe the diverse signs or symptoms that have been experienced by flight crews during or after a training session in a flight simulator[111].
>
> A subtle distinction has been made between true motion sickness (MS) and SS…If a particular flight profile in an aircraft causes discomfort, this is MS. If the same profile is simulated veridically in a simulator, with the same physical force present, and discomfort is caused, technically this is still MS. If a particular flight profile in the aircraft does not cause discomfort, but when simulated it does, this is SS[112].

SS related symptoms are mostly fatigue, eyestrain, headache, difficulty focusing, sweating, nausea, and stomach awareness[113]. Besides the physical condition of an individual, higher latency rates (e.g. >200 millisecond) in FS visual systems might also trigger SS symptoms[114]. It is quite obvious that pilots that experience severe SS would not prefer flying in FS, and this would create resistance against the use of FTSET. Based

111 M. E. McCauley (ed.), Research issues in a simulator sickness: Proceedings of a workshop (Washington, D.C.: National Academy Press, 1984) quoted in David M. Johnson, "Introduction to and Review of Simulator Sickness Research," Research Report 1832, (April 2005): 22.

112 David M. Johnson, "Introduction to and Review of Simulator Sickness Research," Research Report 1832, (April 2005): 22.

113 Ibid.28.

114 Aydın Lafçı, "The Importance of Simulator Usage in TUAA Flight Combat Readiness Training and determining the optimum usage rates" (M.S. thesis, Turkish Military Academy Defense Sciences Institute of Technology Management, 2005): 44.

on questionnaire results (Chappelow, 1988), 4% of pilots who experienced SS symptoms, reported that their experience decreased their willingness to use FS again[115]. Also, based on two different research reports: 8% of pilots reported that SS symptoms lasted longer than 6 hours (Baltzley et al., 1989)[116], and 11% of pilots reported that they experienced delayed effects after training in FS (Crowley, 1987)[117], respectively.

As discussed in the previous paragraphs, SS is a fact and should be incorporated into the model. We consider this factor significant since the effects of SS could last for hours and might inhibit simulator-based training[118]

2. Disagreement in Use of FTSET: The other technology resistance factor is directly related to the concept of using FTSET in flight training. The responses offered in a survey (Lafçı, 2005) - applied to 145 TUAA pilots, showed that 9.7% of the pilots never agreed that they could get the same capabilities in a FS as they could gain in a real aircraft[119]

The Transfer of Training section is comprised of the following subfactors: Appropriate Use of Training Environment, Cumulative Transfer Effectiveness Ratio, Effective Learning, and Favorable Transfer of Training. Each of these subfactors is described as follows:

a. Appropriate Use of Training Environment: This subfactor has two components, technical expertise (while operating and maintaining the FTSET), and training management expertise. These two elements are considered critical in the

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115 J. W. Chappelow, Simulator Sickness in the Royal Air Force: A survey. In AGARD, Motion Cues in Flight Simulation and Simulator Induced Sickness, (AGARD Conference Proceedings, Neuilly Sur Seine, France, Advisory Group for Aerospace Research and Development, 1988) cited in David M. Johnson, "Introduction to and Review of Simulator Sickness Research," Research Report 1832, (April 2005): 46.

116 D.R. Baltzley, R.S et al., The Time Course of Postflight Simulator Sickness Symptoms, (Aviation, Space, and Environmental Medicine, 1989) cited in David M. Johnson, "Introduction to and Review of Simulator Sickness Research," Research Report 1832, (April 2005): 35.

117 J. S. Crowley, and D.W. Gower, Simulator Sickness, (United States Army Aviation Digest, 1988) cited in David M. Johnson, "Introduction to and Review of Simulator Sickness Research," Research Report 1832, (April 2005): 35.

118 David M. Johnson, "Introduction to and Review of Simulator Sickness Research," Research Report 1832, (April 2005): 23-24.

119Aydın Lafçı, "The Importance of Simulator Usage in TUAA Flight Combat Readiness Training and determining the optimum usage rates" (M.S. thesis, Turkish Military Academy Defense Sciences Institute of Technology Management, 2005): 90.

development of an appropriate training environment, and have an impact on Effective Learning.

b. Cumulative Transfer Effectiveness Ratio (CTER)[120]: This ratio is one of the determinants of Effective Learning and thus Favorable Transfer of Training (FTT). CTER is based on the savings incurred from actual flight hours for each hour of training practiced on a FS. The hypothetical relationship between actual and synthetic flight has been studied in the literature (Rantanen & Talleur, 2005; Stewart III, Dohme and Nullmeyer, 1999) and is shown in Figure 11.

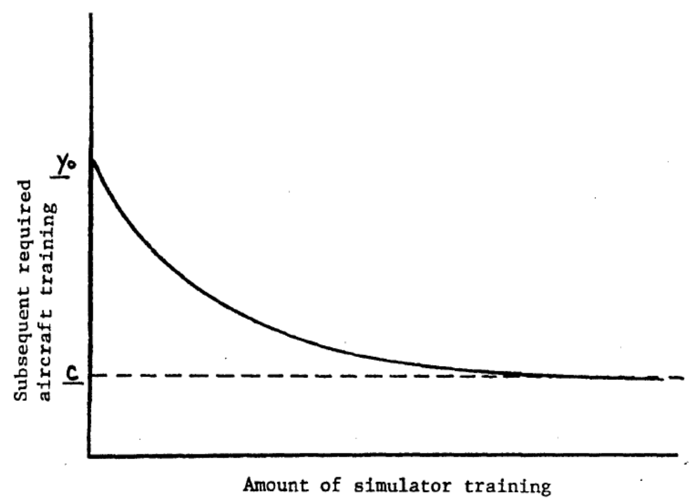

Figure 11. Hypothetical Relationship between Simulator PreTraining and Required Aircraft Training[121].

As simulator pretraining increases, the aircraft training required to meet criterion decreases, thus Yo – C represents the potential savings in aircraft costs that will be realized as the result of simulator pretraining[122].

120 John E. Stewart III, John A. Dohme, and Robert T. Nullmeyer, "Optimizing Simulator-Aircraft Mix for US Army Initial Entry Rotary Wing Training," Technical Report 1092 (March 1999)

121 W. R. Bickely, Training Device Effectiveness: Formulation and Evaluation of a Methodology, (Alexandria, VA: US Army Research Institute for the Behavioral and Social Sciences, 1980), adapted and cited in John E. Stewart III, John A. Dohme, and Robert T. Nullmeyer, "Optimizing Simulator-Aircraft Mix for US Army Initial Entry Rotary Wing Training," Technical Report 1092 (March 1999): 13.

122 John E. Stewart III, John A. Dohme, and Robert T. Nullmeyer, "Optimizing Simulator-Aircraft Mix for US Army Initial Entry Rotary Wing Training," Technical Report 1092 (March 1999): 13.

Accordingly, it is expected that the benefits derived from a SF decreases to a point where the marginal benefit is equal to zero. The following CTER Equation (0.6) has been proposed by Roscoe (1971) to measure transfer effectiveness[123]:

$$\text{CTER} = \frac{(\text{Yo-Yi})}{\text{Xi}} \tag{0.6}$$

> where Xi represents the number of iterations performed in a simulator, Yi is the number of iterations needed in the aircraft to demonstrate criterion performance after Xi simulator training, and Yo is the number of iterations that would be required in the aircraft if no simulator were available[124].

Examining the relationship between synthetic flight, actual flight, and the CTER equation, suggests that we can adapt hypothetical CTER data to our FTSET AP model. This is because actual FTSET usage rates were considered applicable to the CTER data. Figure 12 shows the variation in the CTER between 1990 and 2006 for TUAA FTSET use.

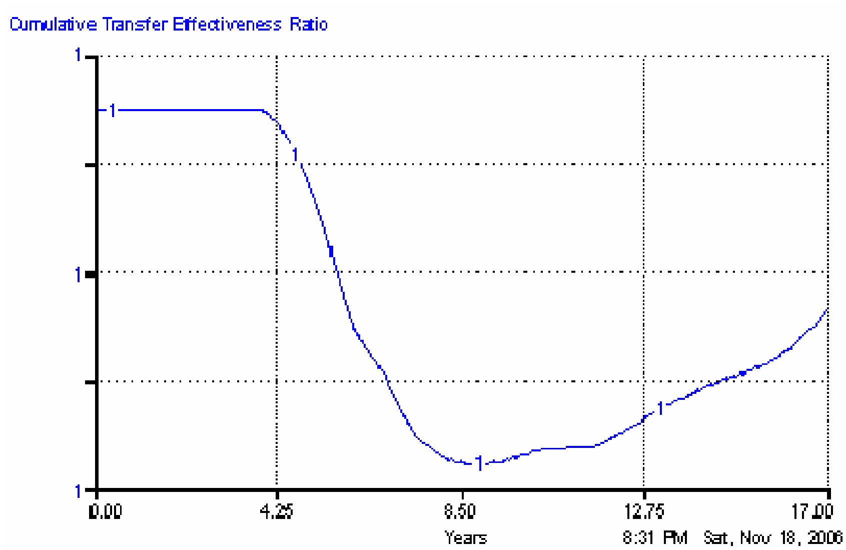

Figure 12. Cumulative Transfer Effectiveness Ratio (CTER) Based on Actual FTSET Use between 1990 and 2006 (Adapted from Stewart III, 1999)

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123 S. N. Roscoe and B. H. Williges, "Measurement of Transfer of Training," Iowa State University Press, Aviation Psychology, (1980) cited in John E. Stewart III, John A. Dohme, and Robert T. Nullmeyer, "Optimizing Simulator-Aircraft Mix for US Army Initial Entry Rotary Wing Training," Technical Report 1092 (March 1999): 11.

124 John E. Stewart III, John A. Dohme, and Robert T. Nullmeyer, "Optimizing Simulator-Aircraft Mix for US Army Initial Entry Rotary Wing Training," Technical Report 1092 (March 1999): 11

c. Effective Learning: This subfactor is determined by the CTER and Appropriate Use of Training Environment. We believe that these two subfactors are the minimum requirements to generate effective learning. That in turn generates the Favorable Transfer of Training.

d. Favorable Transfer of Training (FTT): This subfactor represents Confirmation and Routinization stages of Individual Based and Organization Based Innovation Adoption Models. Once FTT starts to increase, both pilots and organization start begin rationalizing helicopter FS usage and its benefits in a more positive manner. FTT is the most significant metric while measuring the success of training.

Higher FTT is an incentive for the end-user to seek more opportunities towards the use of FTSET. This behavior is represented by Effect of Customization in our model. It can also be explained by the TAM Model and PU of an end-user. The training value of FTSET provides organizational customization and higher adoption of FTSET and that is, in large part, derived from the instructional design and content rather than simulation hardware and software that emulate the functionality of the aircraft[125]

The Customization section is comprised of three sub factors: Minimum Target of Use, Mission Intensity Level, and Effect of Customization. Each of these subfactors is described as follows:

a. Minimum Target of Use (MTU): This subfactor represents the TUAA's organizational intention to use FTSET at least at a certain percentage without any quality concern. Based on the determined life cycle and the incurred costs of the acquired technology, the FTSET should recover its fixed cost, variable costs, and the overhead costs (calculations made are based on a 30-year basis). In our case, this is called Breakeven Percentage of Use (BPU) and is derived from Equation (0.7) below and computed as 37% of the Acquired Technology support:

$$\text{Breakeven Percentage of Use} = (P - V)Q - F \times \text{Acquired Technology} \tag{0.7}$$

[125] Michael E. McCauley, "Do Army Helicopter Training Simulators Need Motion Bases," Technical Report 1176, (February 2006): 4.

where P represents actual flight cost/hour, V is the variable cost/hour, Q is the total FS cabin hours, and F represents the system acquisition cost of the system and referred to as a fixed cost which was incurred upfront.

b. Mission Intensity Level (MIL): This subfactor represents a percentage proportionally assigned to each year's actual flight level for an associated aircraft. By examining Figure 13 the intensity of the mission level and the evolution of actual flights over time are represented. It is important to include the probable impact of mission intensity level since higher intensity levels constrain FTSET usage of field units.

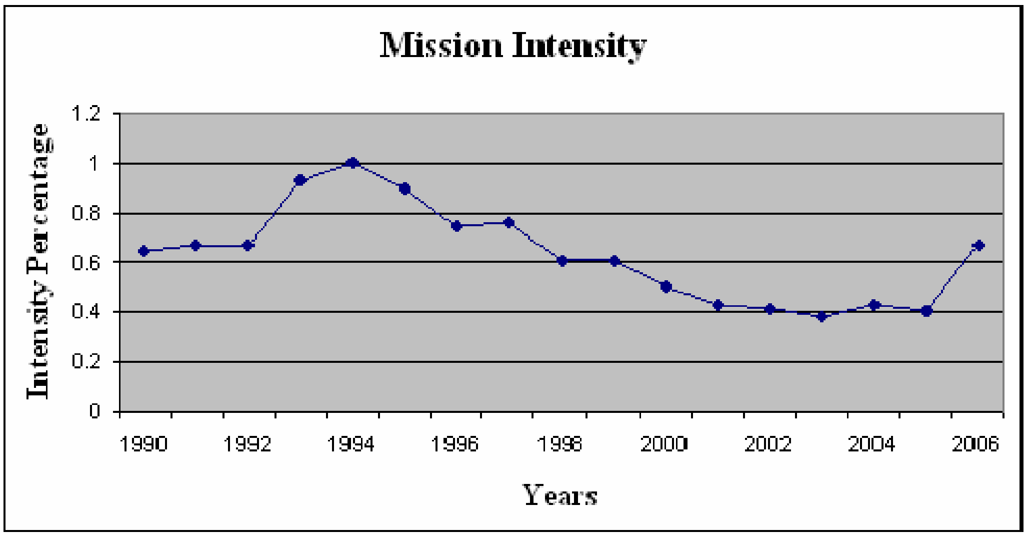

Figure 13. Mission Intensity Level over Time for the Associated Aircraft

c. Effect of Customization (EOC): This subfactor is determined from three main components. These components are human-, authority- (organization), and conjecture-rooted causalities. Human-rooted causalities have two determinants; FTA (reinforces by .3 percent), and FTT (reinforces by .7 percent). MTU is authority-rooted and affects the sum of the human-rooted factors by 100%. MIL subtracts from the cumulative of both human- and authority-rooted factors, and therefore, EOC can be represented by Equation (0.8) as follows;

$$\text{Effect of Customization (EOC)} = \left[\text{MTU} \times \left(.3 * \text{FTA} + .7 * \text{FTT} \right) \right] - \text{MIL} \tag{0.8}$$

The Adoption Section is comprised of three sub factors: Usable Technology, Nominal Adoption Rate, and Technology Adoption Rate. Each of these factors can be described as follows:

a. Usable Technology: This subfactor is a measure of result of what has been acquired as a percentage of support less what has been used. Its initial value is referred to as a percentage of support capability of the FTSET, based on a technology once the system acquired in 1990. We assumed that the FTSET could have supported flight training by 19% in case its full capacity was utilized as an initially.

Two metrics were considered when calculating the initial support percentage of the current FTSET. They were service capacity and training support classification (TSC) respectively. The service capacity was based on the FTSET operation time and the number of the cabins. The FTSET operation time includes periodic maintenance interruptions (preventive maintenance). The second metric, TSC, was assigned "0.4" for the current FTSET, since its classification as Level B, according to FAA AC 120-63 Helicopter Simulator Qualification Document (Demir, May 2001), had already been accepted. The scale determining the classifications for FTSET is shown in Table 2. The second column for each FTSET category has been added to represent the assumption that FTSET supports specific military flight drills.

Type of Flight Training Device	Cockpit Procedure Trainer (CPT)	Level A FS		Level B FS		Level C FS		Level D FS	
Technology Support Classification	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9

Table 2. Flight Training Devices' Training Support Classification (TSC) Scale

Based on the considerations made thus far, service capacity and TSC combine together and constitute the initial Usable Technology with a percentage of support of 19%.

b. Nominal Adoption Rate: This subfactor is the acceptable Technology Adoption Rate for an organization to reach in given period of time. In our case, this is two years therefore the applied Nominal Adoption Rate is “0.5”.

c. Technology Adoption Rate: This subfactor is the combination of Nominal Adoption Rate and EOC. The Technology Adoption Rate withdraws a percentage of support from the Usable Technology pool based on its magnitude, which is determined from the EOC, Nominal Adoption Rate, and the level of Technology Usable. It decays in the same direction as Technology Usable.

3. Sector 3: Technology Discarding

In this sector, there are two main sections: Technology Obsolescence and Technology Discarding. The Technology Obsolescence section is comprised of the following subfactors: Inherent System Availability, Logistics Cycle Time Differential, and Technology Obsolescence Rate. Technology Discarding Sector and its subfactors are demonstrated in Figure 14.

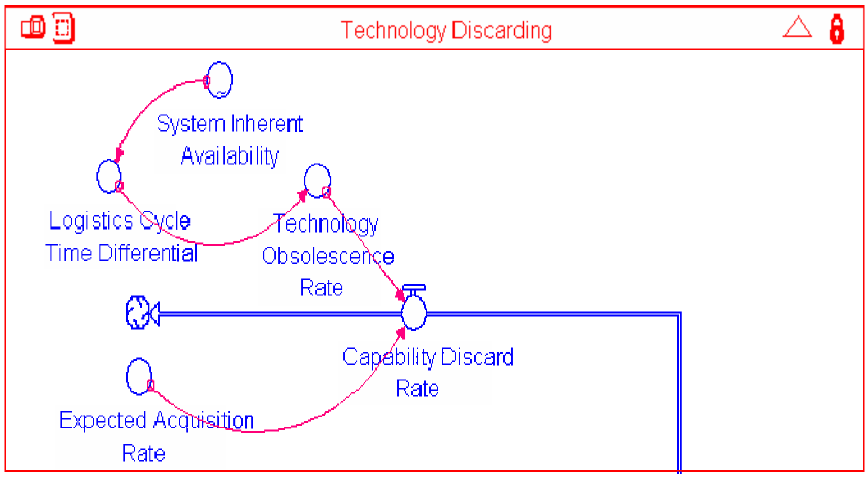

Figure 14. FTSET AP Model Technology Discarding Sector

Each subfactor in this sector is discussed in relation to the FTSET AP and is described as follows:

a. System Inherent Availability[126]: This subfactor is the probability that a system, when used under stated conditions in an ideal support environment, will operate satisfactorily, at any time. It excludes periodic maintenance and logistics delay time[127]. Based on failure statistics (Table 3), Reliability Factor (λ), Mean Time between Failures ($1/\lambda$), Mean Corrective Maintenance Time (Mct), and Inherent Availability Ratio (IAR) were calculated and shown in Table 4.

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[126] Naval Postgraduate School / Graduate School of Business Public and Policy - GB4450MN4470: Systems Management Lecture Slides; 8-22 Logistics Test & Evaluation; Strategy Formulation and Implementation Phases.ppt., 11/14/2006.

[127] Logistics Delay Time: Maintenance downtime that includes awaiting parts, test equipment, and transportation.

Failures	Occurrence	Ct	Tct	Cct
Flight Controls	1	1	1	0.25
Indicators	2	0.5	1	0.25
Motion Failures	3	48	144	72
Computer & Interface	5	48	240	240
Electrical	2	3	6	6
Visual System	3	84	252	63
Support Systems	5	48	240	240
Software	1	36	36	36
Instructor Console	2	1.5	3	1.5
Avionics	3	1	3	0.75
Mct				65.975

Table 3. Annual Average Failure Occurrence and Mean Corrective Maintenance (Mct) Time[128] (Units of Hours)

Mct includes failure detection, fault isolation, disassembly to gain access to the faulty item, repair, etc.[129]

$$\text{Inherent Availability (Ai)} = \frac{\text{MTBF}}{\text{MTBF + Mct}} \quad (0.9)$$

Years	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
R.F.(λ)	0.01	0.05	0.05	0.004	0.02	0.02	0.01	0.01	0.01	0.003	0.009	0.002	0.003	0.004	0.003	0.001	0.002
MTBF(1/λ)	76.9	20	21.7	250	43.5	41.7	76.9	167	200	333.3	111.1	500	333.3	250	333.3	1000	500
Mct	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66
IAR	0.54	0.23	0.25	0.791	0.4	0.39	0.54	0.72	0.75	0.835	0.627	0.883	0.835	0.791	0.835	0.938	0.883

Table 4. Inherent Availability Ratio (IAR) over Time

As a variable input, Historical System Inherent Availability has been graphed and inserted into our model, as shown in Figure 15.

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128 Mct: is the composite value of the arithmetic average of individual maintenance cycle times, Ct: Average correction time, Tct: Total Correction Time, Cct: Cabin or System Correction Time.

129 Benjamin S. Blanchard and Wolter J. Fabrycky, *System Engineering and Analysis*, 4th Edition, 2006

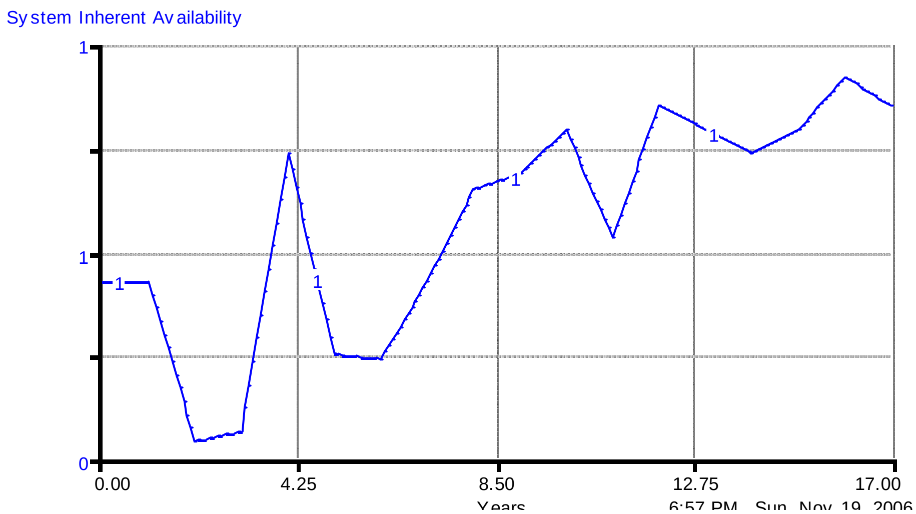

Figure 15. System Inherent Availability over Time in Technology Adoption Model

b. Logistics Cycle Time Differential (LCTD)[130]: This subfactor is a valuable metric that allows technology operators to see how the system differs from ideal support requirements. This in turn shows the time required to maintain and repair the associated FTSET. The lower the cycle time differential the more quickly and consistently the system provides support. As expressed in Equation (0.10), the differential between the FTSET actual and 100% availability determines LCTD in our model.

$$\text{LCTD} = \left(1\text{-IAR}\right) \tag{0.10}$$

c. Technology Obsolescence Rate (TOR): In our study, the TOR is a result of LCTD and its magnitude is also proportional to LCTD. Our analysis determined that the LCTD was the primary determinant of TOR based on this metric would help us to determine to what extent our technology is obsolete or viable during its life cycle[131]. Logistics cycle time (LCT) and evolutionary cycle time[132] (ECT) are complementary,

[130] Brian Brodfuehrer, "Cycle Time Reduction: A Total Systems Life Cycle View on Reducing Cycle Time," *PM* (May-June 2000): 23.

[131] Tom Herald, "Integration of Technology Assessment and Management Methodology for System Sustainment Determination," *International Council on Systems Engineering (INCOSE)* (11 Aug 2005),

<http://www.incose.org/practice/research/seanet_herald.aspx> (26 July 2006)

[132] Evolutionary Cycle Time (ECT): The time it takes to improve or upgrade the system to respond to new threats or requirements. Brian Brodfuehrer, "Cycle Time Reduction: A Total Systems Life Cycle View on Reducing Cycle Time," *PM* (May-June 2000): 23.

and these two determine technology obsolescence[133]. However, we did not include ECT into our model since we could not determine a metric to measure the difference between the ECTs of the current system and of the cutting-edge technology.

Technology Discarding section is comprised of the following subfactors: Expected Acquisition Rate, and Capability Discard Rate respectively. Each of these factors is described as follows:

a. Expected Acquisition Rate: This subfactor monitors the Technology Acquisition Rate and provides continuous information to the Capability Discard Rate. This information link helps the organization decide technology discarding in a timely manner. This is a significant factor in the avoidance of interruptions in the technology support process. Here, we use a smoothing function in Equation (0.11) to make acquisition rate estimates.. The smoothing period is 10 years. The last 10 years' smoothed average is accepted as an annual Expected Acquisition Rate. That in turn becomes one of the two determinants of Capability Discard Rate.

$$smthn\left(\text{Acquisition Rate, 10, 1}\right) \tag{0.11}$$

b. Capability Discard Rate: This rate has two inputs; Expected Acquisition Rate and Technology Obsolescence Rate. If a part of the technology was discarded as a result of those two inputs, the discarded part would be referred to as an obsolete technology and inadequate percentage of support. Here, the main goal is to remain operationally viable through the full sustainment period of helicopter FS[134].

[133] Tom Herald, "Integration of Technology Assessment and Management Methodology for System Sustainment Determination," *International Council on Systems Engineering (INCOSE)* (11 Aug 2005),

<http://www.incose.org/practice/research/seanet_herald.aspx> (26 July 2006)

[134] Ibid.

B. THE EFFECT OF LEARNING IN THE MODEL: AN EXAMPLE FEEDBACK LOOP

The feedback loop depicted in Figure 16, is more prominent when compared to the other loops in the FTSET AP model. This loop is referred to as positive feedback loop (See Sterman 2000) and generates self-reinforcement towards the use of FTSET. The subfactors contained in this feedback loop may help explain the impact of real life experience and learning, on the FTSET AP.

In Figure 16, FTA and FTT represent the accumulation of an individuals' experiences once they begin start using the FTSET. The PEU and PU (already discussed in section II.A) towards the FTSET are also two important criteria which are continuously evaluated by the end-user throughout the FTSET AP. These criteria determine the level of FTA and FTT in the FTSET AP and these in turn stimulate the Effect of Customization, cause a positive impact on the Technology Adoption Rate and thus amplify the Technology Used.

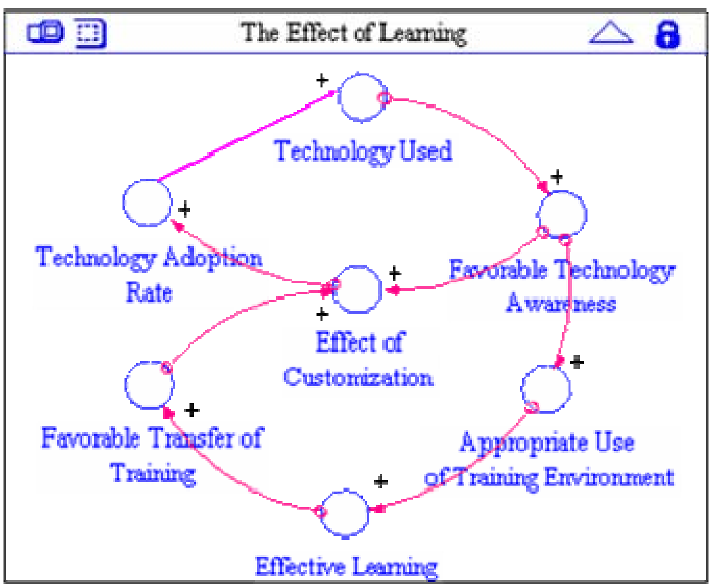

Figure 16. The Effect of Learning: Feedback Loop as a Part of FTSET AP Model

Higher FTA and/or FTT are incentives for the end-user to seek more opportunities that promote the use of FTSET. They are the indirect result of learning. This behavior is represented by the Effect of Customization in the feedback loop (Figure 16). The added value of FTT is also communicated in the TUAA community by word of mouth (social

exposure and imitation)[135] and provides organizational customization and a higher degree of adoption.

Figure 17, demonstrates how FTA and FTT affect the Technology Used. It is noted that these two incentives exponentially increase over the period of the study and they cause an upward trend in the Technology Used. We can infer that learning had an substantial impact on FTSET Support Usage from 1997-2001, resulting in a large increase in its value over the measurement period.

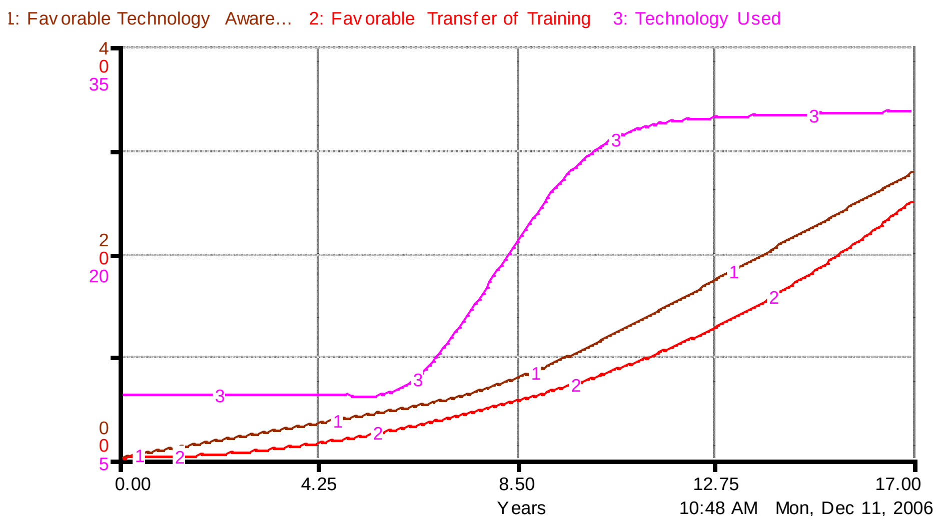

Figure 17. The Comparison of Subfactors: FTA, Appropriate Use of Training Environment, and FTT

135 Potential adopters become aware of the innovation through external information sources such as word of mouth (social exposure and imitation) John D. Sterman, Business Dynamics: Systems Thinking and Modeling for a Complex World (New York: Irwin McGraw-Hill, 2000, 334.

V. DYNAMIC BEHAVIOR AND SENSITIVITY ANALYSIS

A. VALIDATION OF THE MODEL

In order to validate the FTSET AP model, the historical-fit[136] method is employed. We compare the results of the FTSET AP model to the Historical Use of the FTSET Support over a seventeen-year period. Figure 18 exhibits two curves: Technology Used (curve 1) and Historical Support (curve 2). Based on the observation of the two patterns, we infer the following results:

- The FTSET AP Model and the Historical Use of FTSET demonstrate S-shaped behavior and their amplifications are very close: 31.64/9.6=3.29 and 30.21/9.52=3.17 (Table 5), respectively.

- The dynamic behavior observed for the FTSET AP model repeats itself quite similarly for the Historical Use of FTSET.

- Figure 18 and Table 5 exhibit that these two patterns overlap quite closely during the periods from 1993-1996, and 2001-2003.

- The time difference from when the exponential increase starts for each pattern is almost one year. This may be the result of a delay experienced in the historical technology adoption processes.

- Figure 18 and Table 5 exhibit that the periods from 1997-2000 and 2004-2006 do not overlap closely. The reason for the variance during the period from 1997-2000 may stem from the lack of a delay function in the FTSET AP model. The reason for the variance during the period from 2004-2006 may result from the absence of Evolutionary Cycle Time Differential (ECTD) in the FTSET AP model. ECTD might have a role in causing such a variance in the Historical Use of FTSET support since

[136] John D. Sterman, Business Dynamics: Systems Thinking and Modeling for a Complex World (New York: Irwin McGraw-Hill, 2000), 328-331.

ECTD and LCTD are complimentary and the two important determinants of technology obsolescence cited in the literature[137].

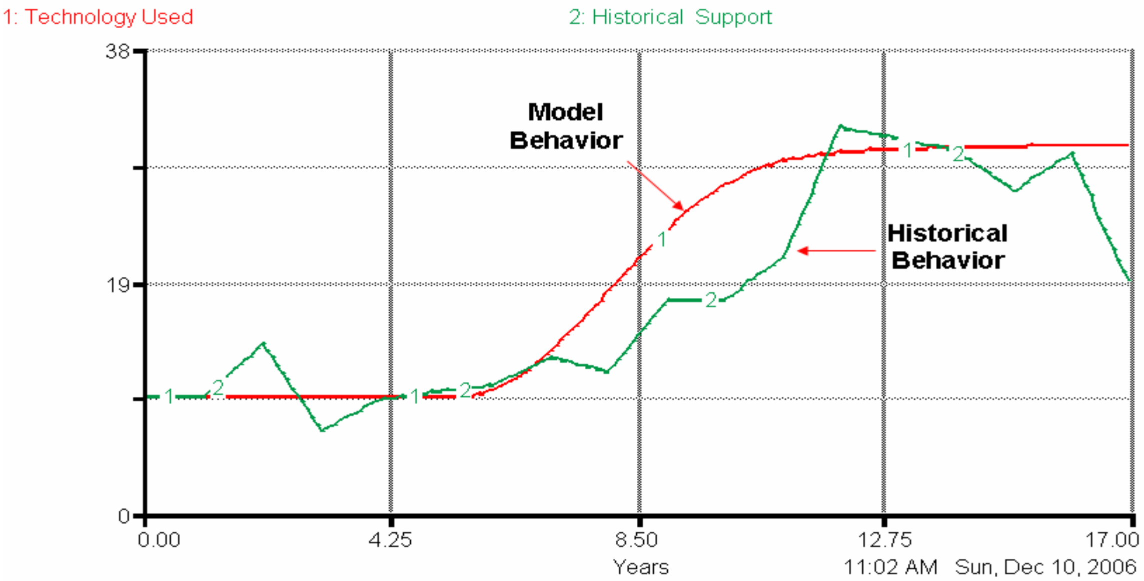

Figure 18. Historical-Fit of the FTSET AP Model

Years	Historical Support	Technology Used
1990	9.6	9.6
1991	13.81	9.58
1992	6.52	9.56
1993	9.19	9.54
1994	9.9	9.52
1995	10.41	10.04
1996	12.7	13.29
1997	11.51	18.18
1998	17.47	23.17
1999	17.46	26.91
2000	20.84	28.85
2001	31.64	29.61
2002	30.74	29.88
2003	29.72	30.01
2004	26.35	30.11
2005	29.44	30.21
2006	18.91	30.3

Table 5. Comparative Use of FTSET

[137] Brian Brodfuehrer, "Cycle Time Reduction: A Total Systems Life Cycle View on Reducing Cycle Time," *PM* (May-June 2000): 23.

B. DYNAMIC BEHAVIOR

In the previous chapters, we discussed existing adoption models and their association with the FTSET AP, and the structure of our FTSET AP model. In this chapter, we discuss execution of the model, and analyze its dynamic behavior.

Figure 19 depicts model results that assess individual perceptions and the organizational culture towards the use of FTSET, variables that we have found to be significant for the TUAA FTSET AP. These two variables become more significant as the technology usage increases. In the model, their associated subfactors are Minimum Target of Use (MTU), Favorable Technology Awareness (FTA) and Appropriate Use of Training Environment.

Throughout the simulation period (1990-2006), increasing trends are observed for these three subfactors. MTU and Appropriate Use of Training Environment explain more committed organizational intention and greater capability towards the use of FTSET. The FTA pattern demonstrates the outcome of a favorable end-user perception towards FTSET. Most of the time, the latter occurs indirectly among the individuals, becomes one of the determinants of the FTSET AP, and constitutes a basis for understanding TUAA organizational culture towards the use of FTSET.

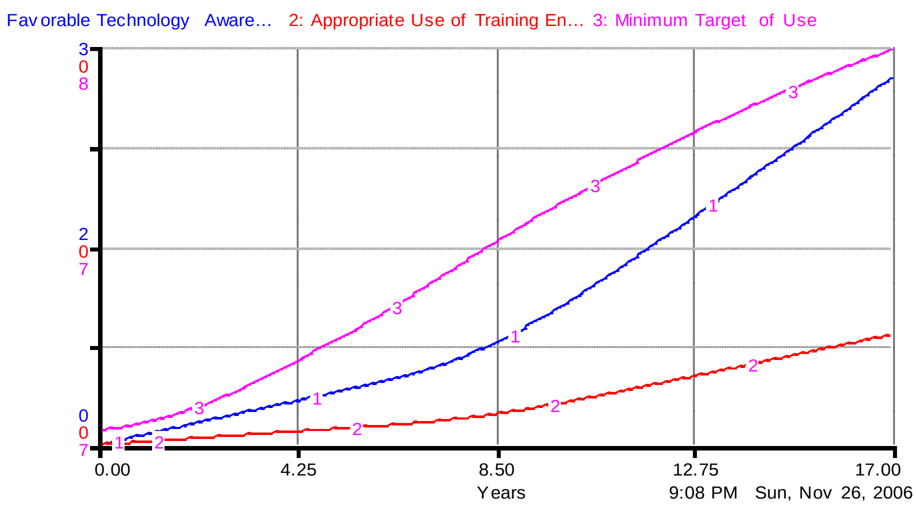

Figure 19. Individual Perceptions and Organizational Culture Development Towards the Use of FTSET

Contrary to expectation, the first six years of Historical Use of FTSET Support, 1990-1995 period, in Figure 20, demonstrate no increase in any of three important

technology adoption parameters; Effect of Customization, Technology Adoption Rate, and Technology Used. It is also noted that Technology Used remains stable, at approximately 10%, until 1996. This stability is driven by two factors: 1) the FTSET was utilized mostly in candidate pilots training curriculums on a regular basis; 2) the lack of organizational culture towards the use of FTSET due to a relatively low initial field pilots' usage level for these years.

However, all three subfactors in Figure 20 exhibit a substantial increase following these first six years, with Technology Adoption Rate reaching its peak during the period from 1997-1998. What triggers such an increase in the Technology Adoption Rate after the first six years is assumed to be the perceived usefulness of FTSET recognized by the end-user. The perceived usefulness of the FTSET generates organizational change, leading to institutionalized technical and management expertise on the FTSET usage.

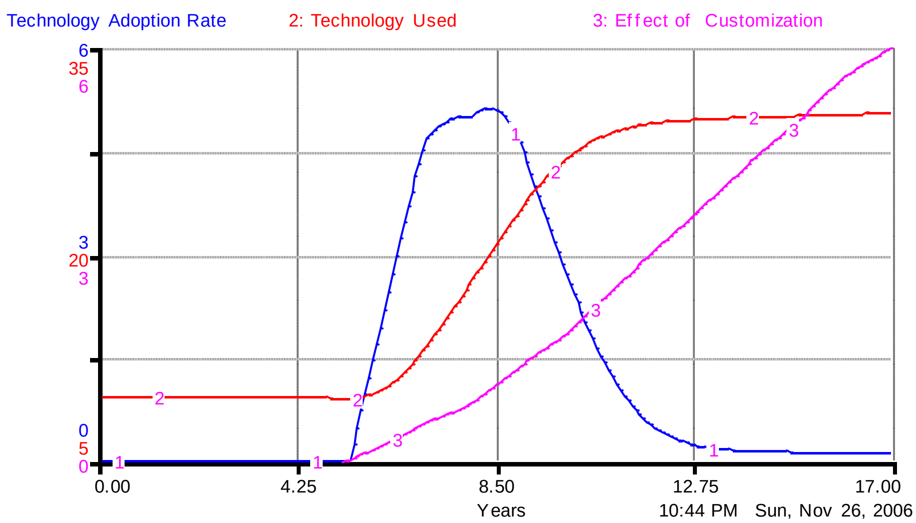

Figure 20. Three Significant Parameters in FTSET Adoption over Time

Another noticeable behavior observed in Figure 20 is the leveling off of the Technology Used in the last six year period, 2001-2006. The Technology Used stabilizes around 30%. Another observation is that the Technology Adoption Rate reaches a climax eight to nine years after system installation. This can be explained by the effect of balancing (negative) factors; system's limited technical capability and its sole support for one type of helicopter. These two factors seem to start dominating the FTSET usage and

take over from the reinforcing (positive) factor, perceived usefulness. In the next sections, these behavioral patterns and the associated model results are tested.

C. SENSITIVITY ANALYSIS

In this section, sensitivity analyses are conducted to determine whether the FTSET AP model results differ significantly when the input variables are varied and the degree to which these results change. This is necessary to test the robustness of our results. Three types of sensitivity[138] are considered in testing our model and they are: numerical, behavior mode, and policy sensitivity. The sensitivity tests applied, together with their analyses are as follows:

1. Funding Rate (FR) Impact

The FR Impact on the FTSET AP model is measured by changing its base case value of 90% (2), to 45% (1). Figure 21 demonstrates the significance of this change by plotting the Technology Used for each case.

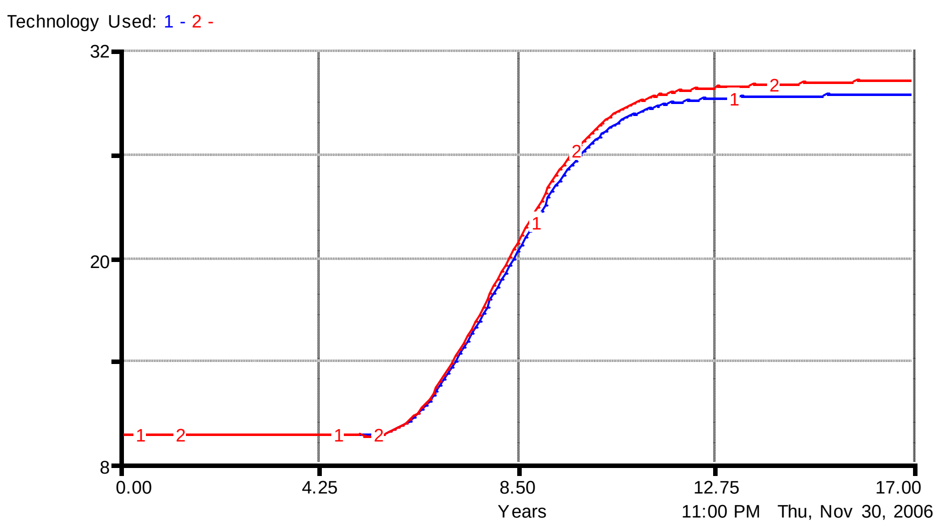

Figure 21. FR Impact on the Technology Used

Figure 21 reveals that the Technology Used is not very sensitive to change in the FR. Curve 1 differs from the base line trend by only 1%. Therefore, we infer that the

[138] Numerical Sensitivity exists when a change in assumptions changes the numerical values of the results. Behavior Mode Sensitivity exists when a change in assumptions changes the patterns of behavior generated by the model. Policy Sensitivity exists when a change in assumptions reverses the impacts of desirability of a proposed policy. John D. Sterman, Business Dynamics: Systems Thinking and Modeling for a Complex World (New York: Irwin McGraw-Hill, 2000), 883.

Technology Used is only slightly numerically sensitive to changes in the FR. As a result of this test, no change is experienced in behavioral pattern and the result does not affect the policy.

The insensitivity of the FTSET AP model to a change in the FR can be explained by at least two reasons: 1) The FR and the acquisitions associated with relatively minor system or service purchases vice huge system procurements. So, a change in the FR may not create a large difference in the Technology Used, especially in the short-run. 2) Technological capability is maintained well and it is preserved in the system, to a certain extent. Otherwise, the Technology Used should have deteriorated over time in the 45% FR situation.

The second part of the test scrutinizes the behavior mentioned in the previous paragraph. Figure 22 shows the evolution of the Capability Discard Rate over time. A 0% FR (curve 1) changes the behavior of the Discard Rate significantly. A 45% FR (curve 2) has no impact on the behavior but on the magnitude of the base case value of 90% FR. (curve 3). This shows the Capability Discard Rate is a rule-based subfactor which follows the Technology Acquisition Rate and determines technology discarding, accordingly.

Change in the Capability Discard Rate might have been larger if another effect, Evolutionary Cycle Time Differential (ECTD), had been included as a subfactor in the model (see section IV.A.3.c.) This in turn might have increased Capability Discard Rate and thus resulted in a higher change in the magnitude of Technology Used in the 45% FR case (Figure 21).

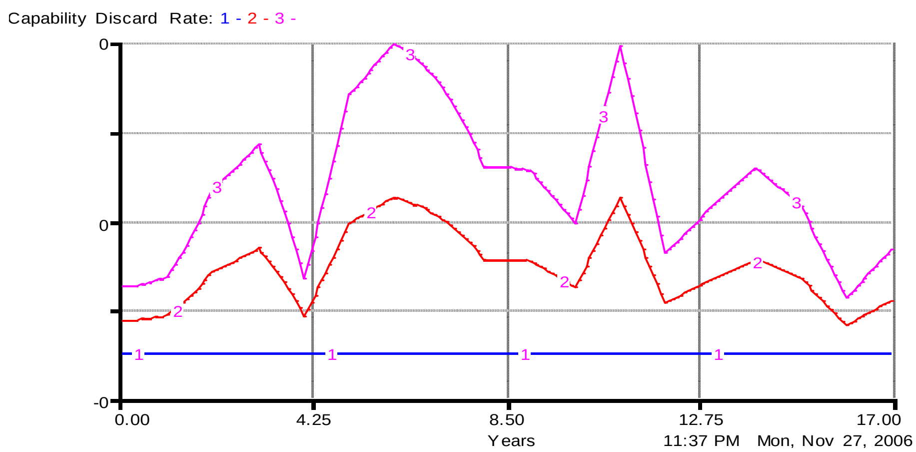

Figure 22. FR Impact on the Capability Discard Rate

2. Minimum Target of Use (MTU) Impact

Sensitivity of the MTU impact on the FTSET AP model is measured by changing the base case value of 37% (curve 1), to 59% (curve 2) and 19% (curve 3). Figure 23 demonstrates the significance of these changes on the Technology Used.

From Figure 23, it is noticed that the Technology Used is insensitive to changes in the MTU since both trends (curve 2 and 3) have S-shaped patterns with a slight difference of 1% at most among the values of the curves, 1, 2, and 3. One significant test result is the difference in timing for each S-shaped pattern. Figure 23 shows that curve 2 starts its increasing trend about three years earlier than the base line trend, curve 1. Curve 3 begins its increasing trend about three years after the base line trend.

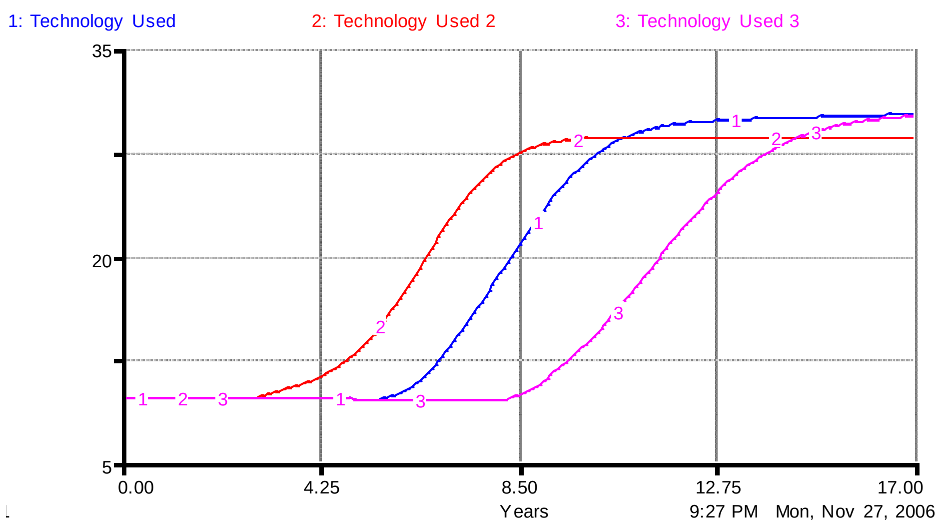

Figure 23. MTU Impact on the Technology Used

Based on these test results, no change is experienced in behavioral patterns but the baseline policy (curve 1) might be changed since a 50% increase (from 37% to 59%) in the MTU causes the FTSET adoption process to begin its exponential increase trend three years earlier than the base line trend's. Regarding the system's life-cycle, an earlier FTSET adoption might generate two important outcomes: the first is creation of greater cost savings and improved flight safety; the second is gaining the maximum benefit from a FTSET before its obsolescence (See Herald 2005). This principle also represents the

implementation and the routinization steps of the Hage and Aiken model[139] (section II.B.2.b).

From these results, we can also reason, that, a TUAA MTU policy may lead to some increase in the Technology Used. This increase may be limited to a certain extent, but, by itself, this organization-based policy is not adequate to increase the usage level more than 30%. Here, the bottleneck is assumed to be the technical features of the current FTSET. This also explains the FTSET usage stagnation during the recent years from 2001-2006 (Figure 6 and 20).

3. Favorable Technology Awareness (FTA) Impact

Sensitivity of the FTA Impact on the FTSET AP model is measured by changing the base case's technology acceptance coefficient, 82% (curve 1), to 100% (curve 2) and 50% (curve 3). Figure 24 and 25 demonstrate the significance of these changes on the Cumulative FTSET Usage and Favorable Transfer of Training (FTT) respectively.

The Cumulative FTSET Usage is the sum of Technology Used between 1990 and 2006. So, the area below each curve in Figure 24 exhibits the total use of FTSET in each case. In other words, the curves explain how much benefit is captured in each trend. Figure 24 shows that Cumulative Usage trends have no behavioral sensitivity but the policy proposed might be based on these results for future benefit.

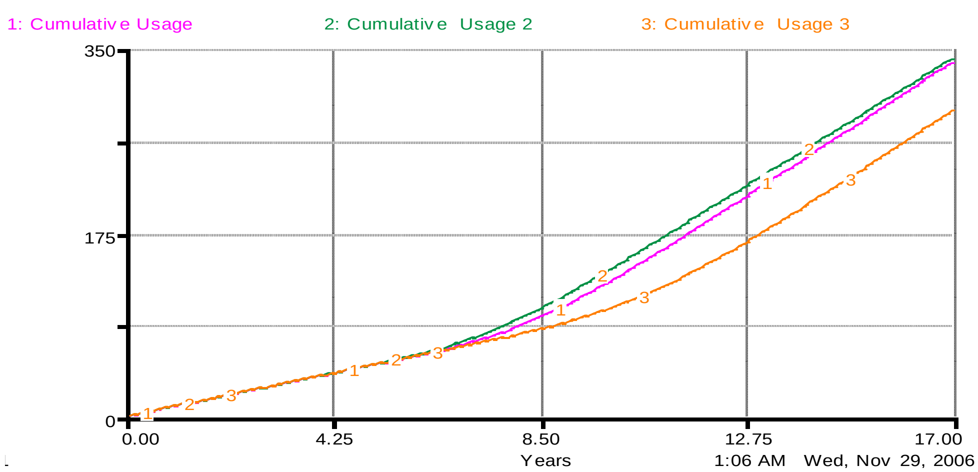

Figure 24. FTA Impact on the Cumulative FTSET Usage

[139] J. Hage and M. Aiken, "Social Change in Complex Organizations," Random House (1970), cited in Mohamed Gamal Aboelmaged: *Researching Information Technology Adoption Process in Higher Education Institutions: A Rational for Applying Individual-Based Models* (Management Science Department: Lancaster University Management School, 2000), 386.

Based on these results, Cumulative Usage 2 captures the most benefit for the seventeen-year period considered in the analysis. Regarding FTA, this is a “no resistance” or a “100% agreement” situation. It requires no technology and/or simulator sickness (SS) related resistance from the end-user. Although this seems improbable, resistance towards the use of FTSET could be reduced to an extent. One way to reduce the resistance is the early involvement of end-users in the acquisition cycle leading to better system design processes and a more favorable attitude towards the use of FTSET (See Al-Gahtani 2003). This also represents one of Roger’s five attributes of Diffusion of Innovation, trialability. Another way to reduce the technology resistance is to search for the opportunities to make the end-user perceive usefulness of the FTSET faster since this would create higher FTA and thus better diffusion of the innovation.

Note that Figure 25 reveals that an increase in the technology acceptance coefficient (compare curve 1, 82% technology acceptance level to curve 2, 100% technology acceptance level) increases FTT. FTT is the primary objective in the flight training and Figure 25 exhibits FTT trends and their exponential increases in each case. The trend number 2 is the most beneficial policy based on the FTSET AP model results.

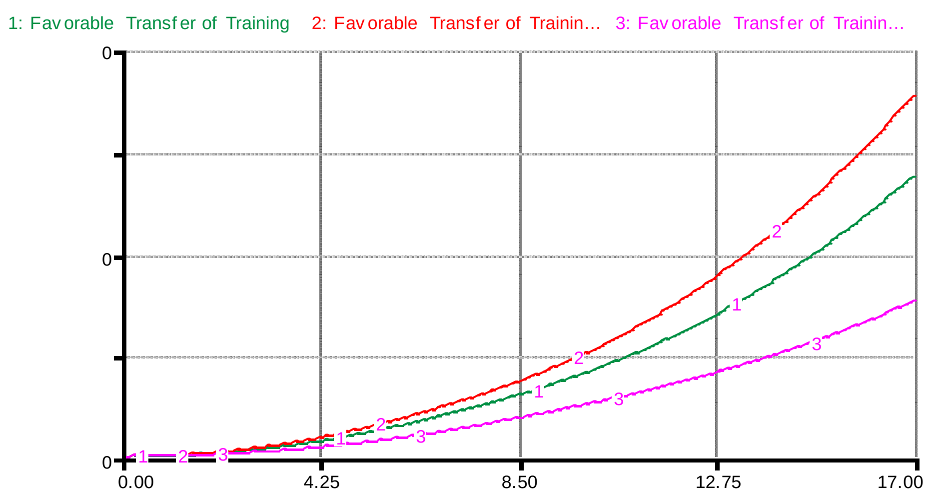

Figure 25. FTA Impact on the Favorable Transfer of Training

4. Training Support Classification (TSC) Rate Impact

Sensitivity of the TSC Impact on the FTSET AP model (discussed in section IV.A.2.a. Usable Technology) is measured by changing the base case's TSC rate of 40% (curve 1), to 20% (curve 2) and 60% (curve 3). Figure 26 demonstrates the significance of these changes on the Technology Used.

Based on these results, it is noted that TSC has a significant qualitative effect on the Technology Used. In each of the three cases, the trends plotted in Figure 26, maintain their S-shaped characteristic. The 20% TSC rate (curve 2) changes the amplification of the base case's Technology Used from 3.29 (31.64/9.6) to 2.02 (19.4/9.6) while the 60% TSC rate (curve 3) increases the amplification of the base case to 4.26 (40.9/9.6). The highest amplification of 4.26 and the curve 3 represents the higher FTSET usage and the technology adoption. This in turn affects the policy as depicted in Figure 26.

In Figure 26, curve 3 demonstrates the steepest S-shaped behavior while curve 2 exhibits the smoothest. This shows that the FTSET adoption is faster when the TSC rate is higher. The use of FTSET also starts its upward trend around 1992 in curve 3, three years earlier than the 1995 point in the base case (curve 1), and five years ahead of the 1997 point in the 20% TSC rate case (curve 2).

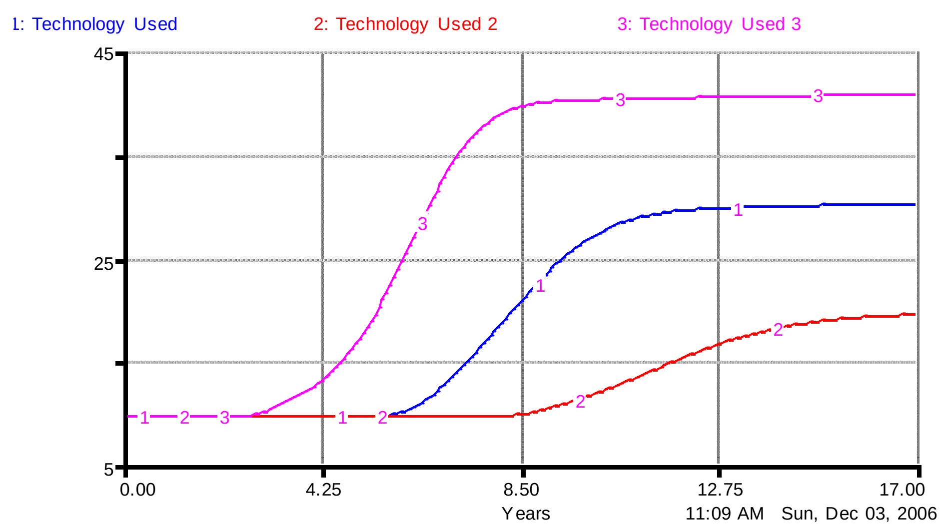

Figure 26. FTSET Training Support Classification (TSC) Impact on the Technology Used

VI. CONCLUSION

A. SUMMARY/POLICY IMPLICATIONS

Today, FTSET supports almost every phase of aviation training in both civil and military applications. The main motivation for using FTSET is to create a cost-efficient and a risk averse training environment. However, the complexity of military aircraft, and military-specific mission flights, and the difficulty of simulating complex mission environments are the main obstacles to the transfer of military training flights to synthetic environment. Deciding on the appropriate mix of synthetic flight training versus actual flight training remains a great unresolved issue in the aviation community.

As in other technology adoption processes, FTSET usage and its adoption levels may vary. Also, it is common to find various FTSET support percentages in different flight training curriculums. In our research, adequate information was discovered for understanding technology adoption and innovation diffusion processes although no specific study could be found on FTSET AP. The TUAA pilots' questionnaire results (Lafçı, 2005), interviews with the end-users, and the various studies[140] [141] [142] conducted by US ARI for the Behavioral and Social Sciences have been found to be significant in the evaluation of some of the FTSET AP model variables during this study.

TUAA has been using FTSET in helicopter flight training since 1990. FTSET usage and its adoption in the TUAA materialized over the one and a half decades and experienced a substantial increase after 1997. In recent years, FTSET usage has stagnated. In this study, we covered three different FTSET Support Usage patterns: initial phase of lower support rates until 1997, followed by substantial increase from 1997-2001, and third phase when growth stagnated during the period 2001-2006. These three phases are our focus areas in this study. Based on the historical S-shaped growth (depicted previously in Figures 3, 6, 18, and 20) and the available sources mentioned previously,

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[140] John E. Stewart III, John A. Dohme, and Robert T. Nullmeyer, "Optimizing Simulator-Aircraft Mix for US Army Initial Entry Rotary Wing Training," Technical Report 1092 (March 1999)

[141] John E. Stewart II et al., eds., "Assessing the Effectiveness of a Low-Cost Simulator for Instrument Training for the TH-67 Helicopter," Research Report 1780 (December 2001)

[142] David M. Johnson, "Introduction to and Review of Simulator Sickness Research," Research Report 1832, (April 2005)

the dynamic hypothesis, model boundary and the variables in the model were determined. Our dynamic hypothesis suggest that these three sequential phases can be explained in terms of an organizational culture towards the use of FTSET, organizational change in favor of FTSET usage and increasing expertise, and system's limited technical capability and its sole support for one type of helicopter respectively.

To test our hypothesis we developed a systems dynamics model of FTSET AP that has three interrelated sectors: Technology Improvement and Acquisition, Technology Adoption, and Technology Discarding. The subfactors in each sector were determined to fit our limited model boundary for this exploratory study.

In conducting this study, we proceeded through eight stages:

1) Reviewing historical development and the implications of FTSET

2) Reviewing systems dynamics model of similar technology adoption processes

3) Relating the methodology of systems thinking and modeling approach to the FTSET AP

4) Associating the FTSET AP with the existing innovation adoption models in the literature

5) Formulating the dynamic hypothesis to explain the behavior of historical FTSET use in the TUAA and determining the boundary of the model

6) Defining the subfactors and the structure of the TUAA FTSET AP model

7) Observing the dynamic behavior, evaluating the robustness of the results and validating the FTSET AP model

8) Making suggestions for policy implications and giving directions for future FTSET AP

Based on the model results, we suggest the following policy considerations for improvements in FTSET AP in the TUAA and prospective FTSET acquisitions:

- Establish higher target level of FTSET Use to initiate an earlier increase in the use of FTSET. This in turn creates more FTSET usage over time and translates into more cost savings, flight safety, and benefit before the acquired FTSET becomes obsolete.

- Shape the training environment to increase the end-users' FTA. This shall create higher rate of increase in FTT. This is the primary aim of the flight training and leads to a greater perceived usefulness of FTSET by the end-users (See Pagani 2004).

- Involve end-users and area experts[143] (Al-Gahtani 2003; Caro 1973) in FTSET acquisition processes, as soon as practicable, to create a better system design, and thus, a higher FTA and less end-user resistance towards the use of FTSET technology.

- Fully understand the end-users' training needs and a Usable Technology[144] to gain maximum benefit from FTSET acquisitions. Here, the optimization of the FTSET usage and technology adoption requires appropriate combinations of FTSET TSC (see Table 2 and Figure 26), affordability, and mission needs. This policy can be maintained by assigning knowledgeable acquisition professionals to FTSET acquisitions and maintaining continuous end-user involvement in in every possible phase of technology acquisition.

- Conform FTSET acquisition cycles to aircraft technology cycles for optimum use of FTSET and higher technology adoption during the life cycle of the FTSET.

B. LESSONS LEARNED

The lack of specific research on the FTSET AP required extrapolation of results from research and analysis of the adoption processes of similar or related technologies.

The location difference between the study executed and the FTSET Usage data source exists limits communication and causes a noise between the researcher and the end-user. This in turn creates a delay during the information gathering.

Technology Improvement and Acquisition Sector variables were particularly difficult to model since they are mostly source-centered innovation adoption process variables. These variables required us to make several assumptions since we were not capable of determining the actual statistics from the literature.

[143] Human Associated Area Experts: Aviation psychologists, behavioral scientists, human factors engineers, etc.

[144] Service capacity (based on number of the cabins and operation hours) and training support classification (TSC) combine together and constitute Usable Technology.

Structural differences in the private and public sector are among the biggest challenges incurred while adapting the Diffusion of Innovations Model to the military culture. This also requires us to include organization-based innovation adoption process variables other than individual-based variables into the FTSET AP model.

The examination of these three types of innovation adoption models (section II.B.1 and II.B.2.a. and b. Existing Adoption Models in SD) and their associated variables, and their incorporation into the FTSET AP model increases the complexity of the modeling process. This in turn imposes a limit on the number of variables to be tested in the sensitivity analyses.

C. CONCLUSION AND SUGGESTIONS FOR FUTURE RESEARCH

1. Conclusions

This project examined the FTSET AP of the TUAA during the period from 1990 to 2006 applying the SD perspective of technology adoption and employing the SD Simulation Model, *Stella Modeling and Simulation Platform*. The objective of this project was to model the FTSET AP of the TUAA, understand the AP and generate policy for prospective FTSET acquisition processes. The historical-fit between our model and the real system demonstrated that the SD perspective of technology adoption and the FTSET AP model is a viable tool to model the FTSET AP.

Based on the sensitivity analyses and the historical-fit runs of the FTSET model results, it is clearly understood that MTU, FTA, and TSC have significant impacts on the FTSET AP while FR results were negligible. MTU affected the timing of increasing trends in the model but had no impact on the magnitude of technology adoption. The FTSET AP model and Cumulative FTSET Usage wee numerically sensitive to FTA impact. FTA also changes the strength of the rate of increase in FTT. We found that TSC generated the biggest impact on the magnitude of technology adoption in the FTSET AP model.

Conducting the study, it is demonstrated that the existing adoption models in SD, SD perspective of technology adoption, and the FTSET AP model can explain the causality among the variables and generate policy implications for future use of FTSET and the prospective FTSET acquisitions.

2. Suggestions for Future Research

The primary suggestion for future research in this area is to conduct additional evaluations of the FTSET AP model and its capacity to replicate real life results. Second, suggestion is to extend the model to take into account conditions and variables such as technology acquisition and discarding delays in the processes, additional organization- and individual-based attitudes, etc. Another suggestion is to develop a metric to include ECTD into the FTSET model. This would preclude determination of the Technology Obsolescence Rate in the model by only the LCTD.

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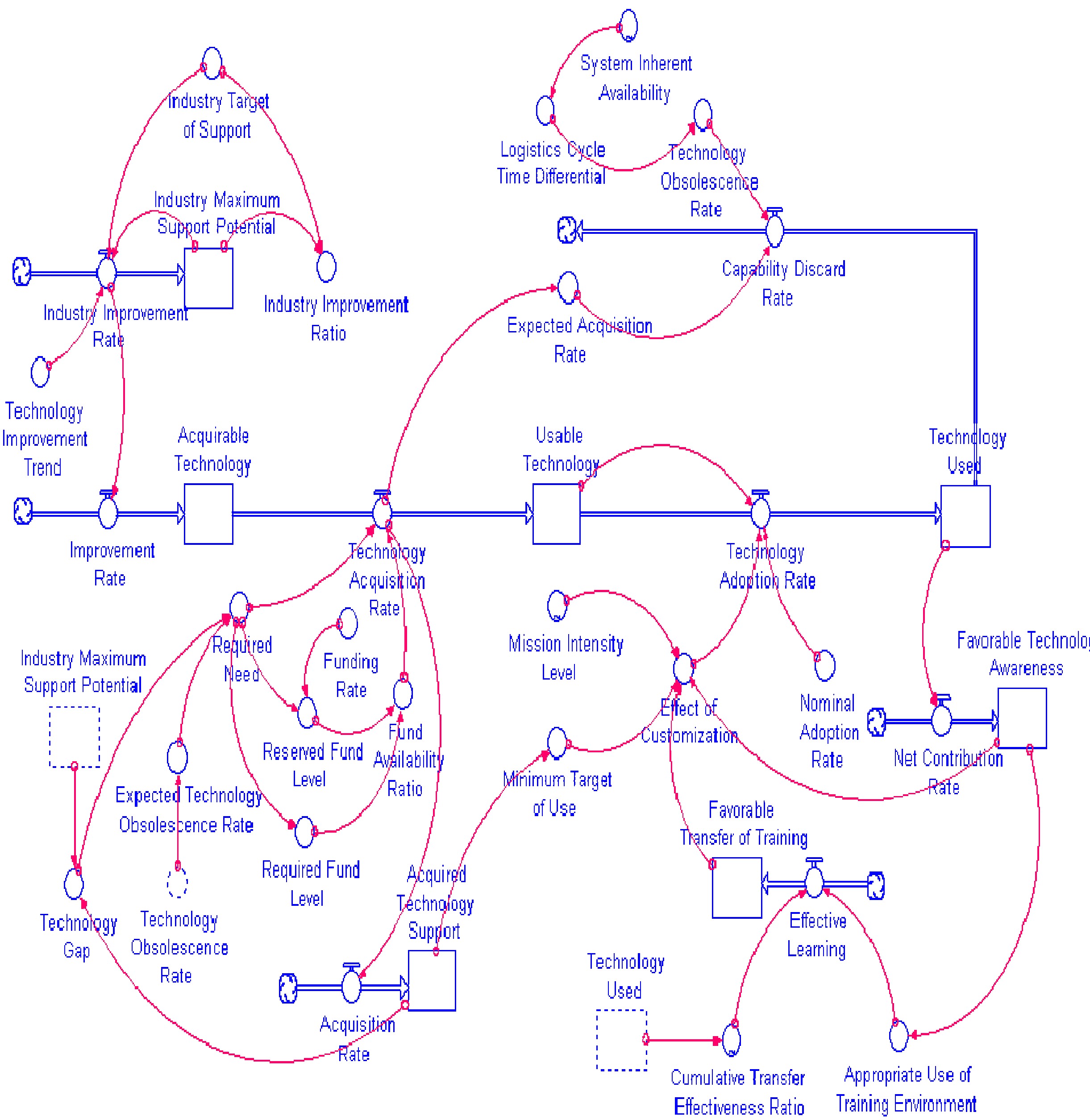
APPENDIX A: THE FTSET AP MODEL STRUCTURE



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APPENDIX B: FORMULAS AND EQUATIONS

Technology Improvement & Acquisition

Acquirable__Technology(t) = Acquirable__Technology(t - dt) + (Improvement_Rate - Technology__Acquisition__Rate) * dt

INIT Acquirable__Technology = 21

INFLOWS:

Improvement_Rate = Industry_Improvement__Rate

OUTFLOWS:

Technology__Acquisition__Rate = (Fund__Availability_Ratio*Required__Need)

Acquired_Technology_Support(t) = Acquired_Technology_Support(t - dt) + (Acquisition_Rate) * dt

INIT Acquired_Technology_Support = 19

INFLOWS:

Acquisition_Rate = Technology__Acquisition__Rate

Industry_Maximum__Support_Potential(t) = Industry_Maximum__Support_Potential(t - dt) + (Industry_Improvement__Rate) * dt

INIT Industry_Maximum__Support_Potential = 21

INFLOWS:

Industry_Improvement__Rate = (Industry_Target_of_Support-Industry_Maximum__Support_Potential)*Technology__Improvement__Trend

Expected_Technology_Obsolescence_Rate = SMTHN(Technology__Obsolescence__Rate,5,1)

Funding_Rate = .9

Fund__Availability_Ratio = Reserved_Fund__Level/Required_Fund_Level

Industry_Improvement__Ratio = (Industry_Maximum__Support_Potential/Industry_Target_of_Support)

Industry_Target_of_Support = 75

Required_Fund_Level = Required__Need

Required__Need = (Technology_Gap*Expected_Technology_Obsolescence_Rate)/100

Reserved_Fund__Level = FORCST(Required__Need,10,1,1.05)*Funding_Rate

Technology_Gap = (Industry_Maximum__Support_Potential-Acquired_Technology_Support)

Technology__Improvement__Trend = .1

Technology Adoption

Favorable_Technology__Awareness(t) = Favorable_Technology__Awareness(t - dt) + (Net_Contribution__Rate) * dt

INIT Favorable_Technology__Awareness = 0

INFLOWS:

Net_Contribution__Rate = (.82*Technology_Used)/100

Favorable__Transfer_of_Training(t) = Favorable__Transfer_of_Training(t - dt) + (Effective__Learning) * dt

INIT Favorable__Transfer_of_Training = (Effective__Learning)

INFLOWS:

Effective__Learning = (Appropriate_Use_of_Training_Environment*Cumulative_Transfer_Effectiveness_Ratio)

Technology_Used(t) = Technology_Used(t - dt) + (Technology_Adoption_Rate - Capability_Discard__Rate) * dt

INIT Technology_Used = 9.6

INFLOWS:

Technology_Adoption_Rate = Nominal__Adoption_Rate*Effect_of__Customization*Usable__Technology

OUTFLOWS:

Capability_Discard__Rate (IN SECTOR: Technology Discarding)

Usable__Technology(t) = Usable__Technology(t - dt) + (Technology__Acquisition__Rate - Technology_Adoption_Rate) * dt

INIT Usable__Technology = 19

INFLOWS:

Technology__Acquisition__Rate (IN SECTOR: Technology Improvement & Acquisition)

OUTFLOWS:

Technology_Adoption_Rate = Nominal__Adoption_Rate*Effect_of__Customization*Usable__Technology

Appropriate_Use_of_Training_Environment = Favorable_Technology__Awareness/100

Effect_of__Customization = (Minimum_Target__of_Use*((.7*Favorable__Transfer_of_Training)+(.3*Favorable_Technology__Awareness)))-(Mission_Intensity__Level)

Minimum_Target__of_Use = (Acquired_Technology_Support*.37)

Nominal__Adoption_Rate = .5

Cumulative_Transfer_Effectiveness_Ratio = GRAPH(Technology_Used)

(10.0, 1.00), (15.0, 0.9), (20.0, 0.8), (25.0, 0.75), (30.0, 0.65), (35.0, 0.6), (40.0, 0.55), (45.0, 0.5), (50.0, 0.45)

Mission_Intensity__Level = GRAPH(time)

(1.00, 0.65), (2.00, 0.674), (3.00, 0.674), (4.00, 0.931), (5.00, 1.00), (6.00, 0.896), (7.00, 0.746), (8.00, 0.761), (9.00, 0.609), (10.0, 0.611), (11.0, 0.5), (12.0, 0.431), (13.0, 0.414), (14.0, 0.383), (15.0, 0.429), (16.0, 0.409), (17.0, 0.672)

Technology Discarding

Capability_Discard__Rate = Expected_Acquisition__Rate*Technology__Obsolescence__Rate

OUTFLOW FROM: Technology_Used (IN SECTOR: Technology Adoption)

Expected_Acquisition__Rate = SMTHN(Technology__Acquisition__Rate,10,1)

Logistics_Cycle__Time_Differential = 1-(System_Inherent_Availability)

Technology__Obsolescence__Rate = (Logistics_Cycle__Time_Differential)

System_Inherent_Availability = GRAPH(time)

(1.00, 0.54), (2.00, 0.23), (3.00, 0.25), (4.00, 0.79), (5.00, 0.4), (6.00, 0.39), (7.00, 0.54), (8.00, 0.72), (9.00, 0.75), (10.0, 0.835), (11.0, 0.627), (12.0, 0.883), (13.0, 0.835), (14.0, 0.791), (15.0, 0.835), (16.0, 0.938), (17.0, 0.883)

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